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Final Report

for

OAQ Data Transmission Study

10 February 1967 - 25 July 1967

Contract No. NAS 5-10509


by

Edward P. Greene

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

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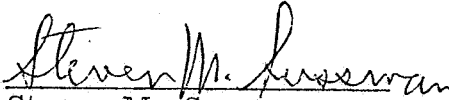
Approved by 
Steven M. Sussman
Director of Research

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1. STUDY OBJECTIVES

This study was conducted to estimate the compressibility of playback SDHE telemetry data from future OAO series satellites and to develop an implementation plan for processing and transmission of the compressed SDHE telemetry data from the data acquisition stations supporting the OAO project to the OAO Control Center at NASA/GSFC.

2. SCOPE OF REPORT

This report contains the results of both Phase I and Phase II of the "OAO Data Compression Study" performed under NAS 5-10509. The technical material presented in this report covers the following major items:

- (1) An analysis of the compressibility of the SDHE telemetry data based upon a detailed examination of this data from the OAO-A1 spacecraft with estimated extrapolations to the case of future OAO spacecrafts;
- (2) An evaluation of three possible conceptual configurations for the data compression and transmission of SDHE data from a Remote Control Station to the OAO Central Control Station over NASCOM Communication Circuits;
- (3) The refinement of the specifications and the performance analysis of the most promising of the three configurations discussed above to include the constraints imposed by existing or planned station equipment, operational procedures and message formats; and
- (4) The development of a proposed approach for the reconstruction of compressed SDHE data within the SDS-930 computer at the OAO Central Control Station.

3. ANALYSIS OF COMPRESSIBILITY OF OAO-SDHE TELEMETRY DATA

3.1 SDHE Telemetry Format

The first step in analyzing the compressibility of the SDHE data was to perform a detailed study of the SDHE telemetry format. Figure 1 is a diagram of the SDHE telemetry format. A frame of telemetry data consists of 65 words of 26 bits each. The first bit of each word may be considered as a filler bit which does not contain any significant information. The 26th bit of each word is an odd parity bit. Thus, the data content of the telemetry word is contained in the remaining 24 bits. The data content of the SDHE telemetry frame can be functionally divided into the following four categories:

- (1) SDHE Telemetry Control (Words 0 to 2).
- (2) Gimbal Data (Words 3 to 26).
- (3) Bi-Level Data (Words 27 to 32).
- (4) Analog Data (Words 33 to 64).

The following section notes certain peculiarities existing within the SDHE telemetry format.

The gimbal angle data (Words 3 to 26) is internally stored within the OSO satellite on a magnetostrictive delay line whose circulation time is asynchronous with the SDHE frame rate. Although each of the 24 gimbal angle measurements will be monitored somewhere within this 24-word field of the SDHE format; the word location is variable and it is necessary to examine the address field of the Word 3 order to determine the order in which the gimbal angle data will be telemetered for the current frame.

The commanded gimbal angle is transmitted in the reverse bit order from that of the rest of the SDHE data. While the Magnavox PCM/DHE is able to handle data received either least significant bit first, or most significant bit first, it is unable to handle a format which contains data in both of these forms.

MAIN FRAME WORD NUMBER	DATA FIELD	INTERNAL WORD FORMAT	COMMENTS
0 (or 65) 1	FRAME SYNC PATTERN IDENTIFICATION AND SPACECRAFT TIME WORD	FIXED 24-BIT PATTERN 12 BIT ID AND 12 BIT TIME FIELD	12 BIT ID FIELD CAN SERVE AS EXTENSION FRAME SYNC PATTERN
2	PROGRAM CODE AND CMAR	16 BIT PROGRAM CODE AND 8 BIT CMAR FIELD	PROGRAM CODE FIELD SPECIFIES SUBCOMMUTATION CYCLE
3 to 26	GIMBAL ANGLE DATA a) GIMBAL COMMAND AND ADDRESS WORDS (ODD MAIN FRAME WORD NUMBERS) b) GIMBAL ERROR AND STATUS WORDS (EVEN MAIN FRAME WORD NUMBERS)	7 BIT GIMBAL ADDRESS 2 BIT BLANK FIELD 15 BIT COMMAND FIELD 5 BIT BLANK FIELD 2 BIT STATUS FIELD 17 BIT ERROR FIELD	COMMAND GIMBAL DATA IS RECEIVED IN REVERSE BIT ORDER FROM REST OF MAIN FRAME DATA. THE ORDER IN WHICH THE GIMBAL DATA IS COMMUTATED ONTO THE MAIN FRAME IS VARIABLE. ADDRESS FIELD OF FIRST GIMBAL COMMAND WORD (MF WORD 3) MUST BE EXAMINED TO DETER- MINE ORDER IN WHICH THESE 24 GIMBAL WORDS WILL BE COM- MUTATED.
27 to 32	BI-LEVEL DATA	24 INDIVIDUAL ONE BIT SENSORS	BI-LEVEL WORDS #5 AND #7 AL- TERNATE SYNCHRONOUSLY ON MF WORD 32. BI-LEVEL WORDS #6 AND #8 AL- TERNATE SYNCHRONOUSLY ON MF WORD 31. FIVE DIFFERENT BI-LEVEL WORDS (4A THRU 4E) ALTERNATE ON MF WORD 30. THREE BITS IN MF WORD 29 SPECIFY WHICH BI-LEVEL WORD WILL BE PRESENT ON MF WORD 30 OF THAT FRAME.
33 to 52	ANALOG DATA a) OPERATIONAL OR EN- VIRONMENTAL SENSORS	THREE 8 BIT DATA SYLLABLES	PROGRAM CODE WORD SPECIFIES WHICH GROUP (OPERATIONAL OR ENVIRONMENTAL) INCLUDED IN FRAME.
53 to 64	b) GROUPS A, B, C OR D	THREE 8 BIT DATA SYLLABLES	PROGRAM CODE WORD SPECIFIES WHICH GROUP (A, B, C OR D) INCLUDED IN FRAME.

Fig. 1 OAO SDHE Telemetry Format

The fourth bi-level word (Word 30) is sub-subcommutated in a peculiar manner. A complete cycle of Word 30 would be: 4A, 4B, 4C, 4D, 4A, 4B, 4C, 4E. To determine the current position of commutation cycle it is necessary to examine three bits contained in the previous bi-level word (Word 29). The fifth and sixth bi-level word (Words 31 and 32) are subcommutated to a single level. However, the subcommutation on these words is synchronous with the main frame. Therefore the Program Code Field of Word 2 will identify the current state of the subcommutation of Words 31 and 32.

3.2 Word Size Consideration for Data Compression

Before attempting to analyze the compressibility of the SDHE data it is necessary to decide on the format of the SDHE data as it enters the data compressor and also the format of the non-redundant compressed data as it leaves the compressor. Since sensor measurement to precision of 1 bit, 8 bits, 12 bits, 15 bits and 17 bits are found in the SDHE format, no single word length would fit all SDHE sensor data in a natural manner. Of course, the compression algorithm and encoding procedure could be implemented to recognize, compress and encode all data points in their natural word length; however, this would greatly complicate the compression and encoding procedure (whether done by hardware or software) and would make data reconstruction by the SDS-930 at OAO Control Center considerably more difficult. In addition, a very severe buffer problem would result during periods of low compressibility if the bi-level data were encoded on the basis of an individual sensor (1-bit). This results from the fact that a minimum of 9 address bits would be required for every non-redundant bi-level data bit.

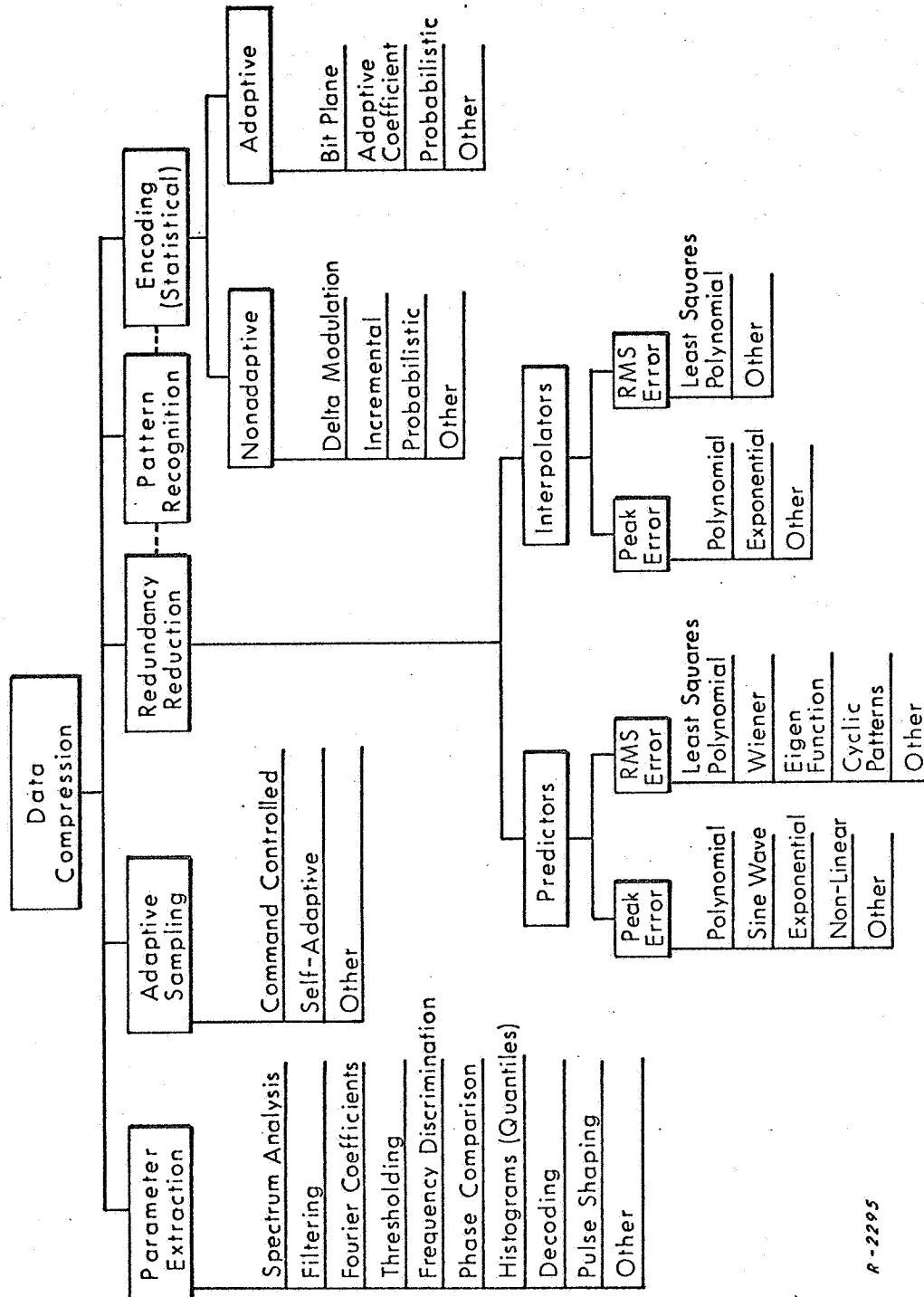
Having rejected the variable word size approach for the compressed data it became apparent that an 8-bit word length was the best choice to satisfy the overall SDHE format requirements. The considerations contributing to that decision were the following:

- 1) All of the analog sensors, which represent half of the SDHE frame, are encoded to 8-bit accuracy.
- 2) By omitting the least significant bit of the error gimbal angle measurements, all gimbal angle parameters can be conveniently subdivided and processed separately as a most significant 8-bit word and a least significant 8-bit word.
- 3) Bi-level pseudo-words of 8-bits can be assembled from 8 bi-level sensor bits and can be processed in that form using a zero aperture tolerance.
- 4) An 8-bit address field will suffice to identify any non-redundant measurement in an SDHE frame provided all measurements are assembled into word lengths not less than 8-bits.

For the above reasons it is recommended that the SDHE data words of 24 information bits be subdivided into three data syllables of 8-bits each and that each syllable be processed independently. Where the assembled 8-bit syllable corresponds to an 8-bit analog measurement or least significant portion of an error gimbal angle, a non-zero data compression aperture may be selected consistent with the fidelity requirements of the reconstructed data. However, for the case of all pseudo-words which represent bi-level data or the most significant portions of more precise measurements, a zero aperture tolerance must be selected in order to assure proper data reconstruction. The output from the data compressor will be a 16-bit non-redundant data word consisting of an 8-bit address field and an 8-bit magnitude.

3.3 Data Compression Algorithms

A number of data compression algorithms have been developed for reducing the bandwidth requirements of telemetry data. References 1 through 4 give a thorough discussion of this topic. Figure 2 shows a breakdown of the various types of data compression algorithms. For the present application we will limit our interest to the redundancy reduction category and specifically to



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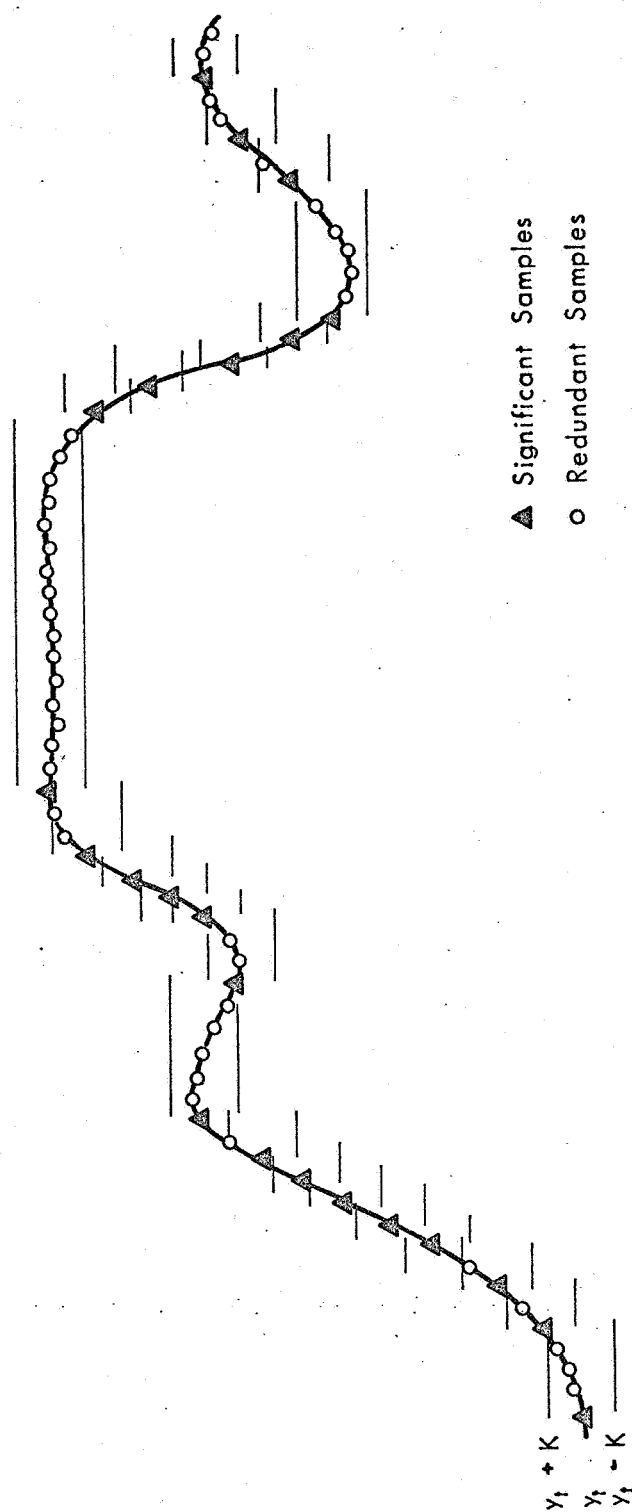
Fig. 2 Classification of Data Compression Models

the polynomial predictors and interpolators. Based upon an evaluation of a number of predictor and interpolator algorithms, it has been found^{2,3} that for most typical telemetry data the two algorithms which perform best from cost-effectiveness considerations are the zero order predictor (ZOP) and the first order interpolators.

Figure 3 is an illustration of the ZOP algorithm. With this algorithm the first data point (y_t) is transmitted and thereafter the algorithm predicts that all subsequent samples will fall within the corridors given by $y_t \pm K$ where K is a predetermined constant for that sensor. If this condition is met, then the received data point is not transmitted. However, whenever the sampled value y_n falls outside the $y_o \pm K$ limits, the new value, y_n , is transmitted and the $\pm K$ aperture limits are then placed around y_n to form the basis for subsequent data sample tests. Figure 3 illustrates the redundant and non-redundant samples obtained using the ZOP algorithm.

The first order interpolator is shown in Fig. 4. In this illustration y_o is a previously transmitted data sample. The first order interpolator algorithm attempts to form the longest possible straight line segment such that the distance from the derived line segment to any one of the received data points along the line does not exceed a predetermined peak error given by $\pm K$. In this illustration the line segment was terminated at y_{t+6} because any attempt to extend the line segment to y_{t+7} or beyond would have violated the previously established error tolerances. A new line segment will be started at y_{t+6} and an appropriate message will be transmitted which will identify the end point of the first segment and the starting point of the next segment.

While the first order interpolator can achieve higher bandwidth reduction than ZOP for certain classes of data, analysis of OAO data revealed that this additional sophistication cannot be justified for this application. Figure 5 illustrates the effect of the ZOP algorithm on an actual sample of telemetry data.



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Fig. 3 Zero Order Predictor (ZOP) Algorithm

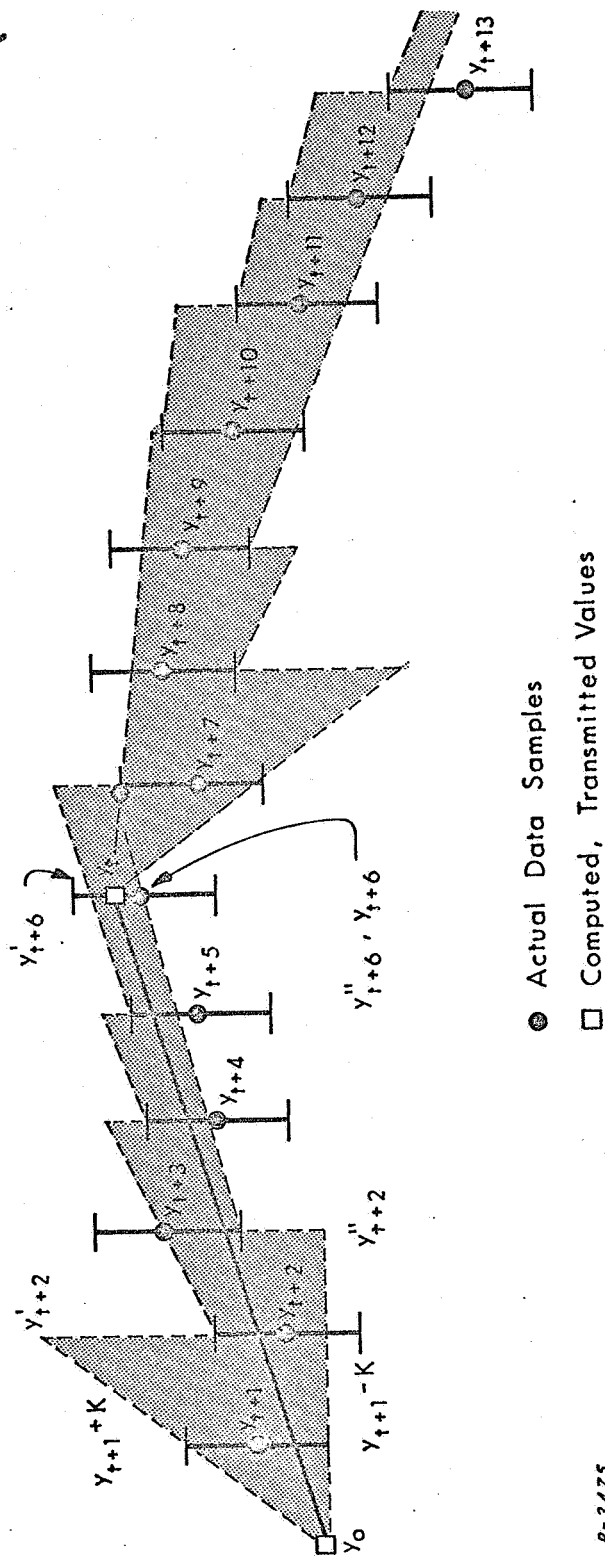


Fig. 4 First Order Interpolator Algorithm

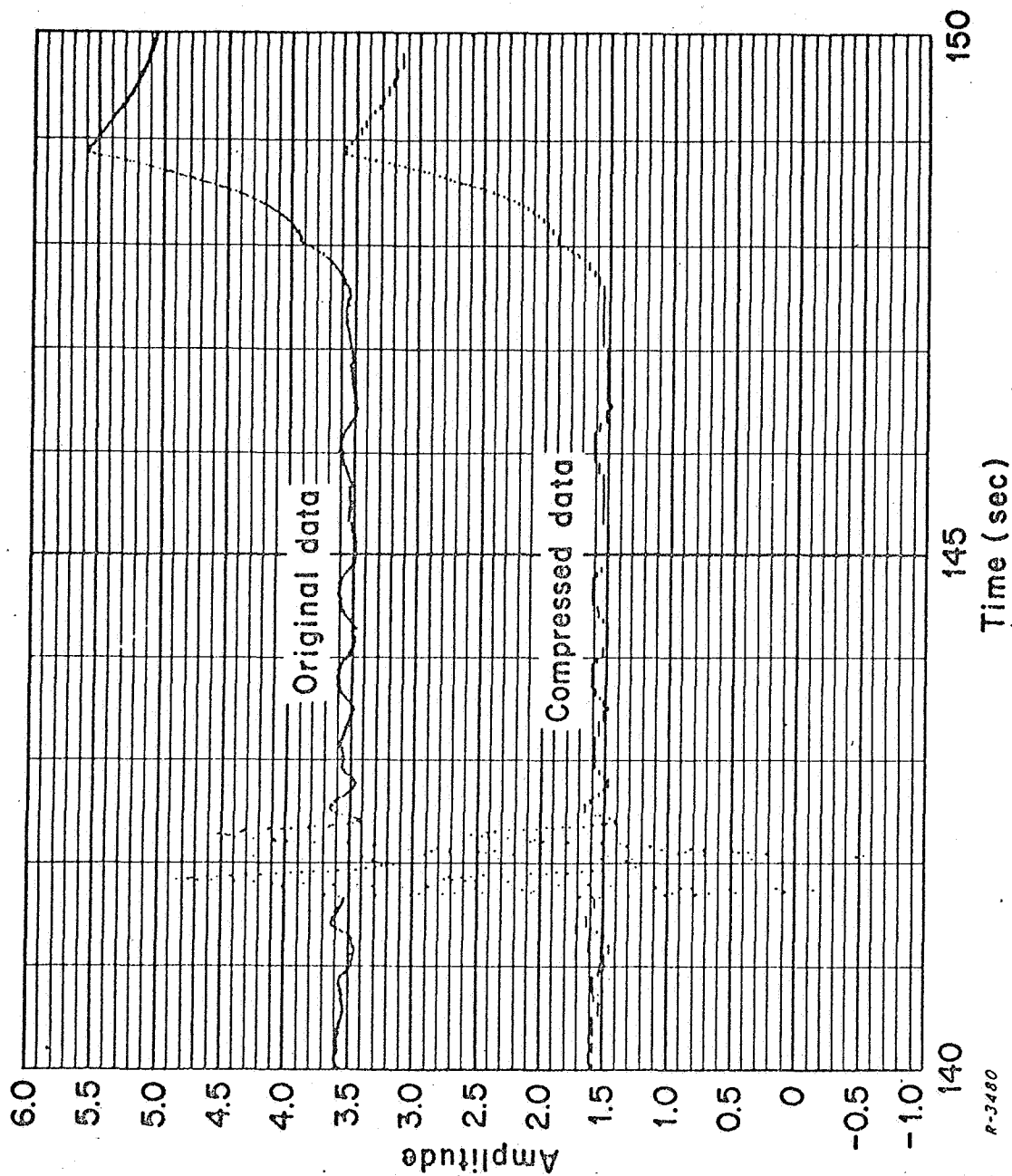


Fig. 5 Comparison of Telemetry Waveform Using ZOP Algorithm. Note Fidelity of Data Reconstruction During Period of High Activity Around $T = 142$ seconds

3.4 Compressibility of SDHE Telemetry Data

An estimate of the compressibility of OAO SDHE telemetry data was obtained from the examination of a 35 mm film supplied by GSFC which contained the actual received waveforms from all the SDHE sensors taken from OAO-A1 on Contacts No. 2, 3, 9, 10, 11, 12, 18 and 19. It was not possible to get an accurate estimate of the normal activity of all SDHE sensors due to the fact that 1) the spacecraft was not properly stabilized during this time period, and 2) short-circuiting had occurred within several strings of telemetry sensors resulting in a number of sensor outputs being tied together. Nevertheless, it was possible to gain considerable insight into the normal functioning of the SDHE sensors which were not affected by the short-circuiting and were not excessively influenced by the lack of proper attitude control.

Early in the investigation it became apparent that the compressibility of the SDHE would be influenced to a considerable extent by the current mode and status of the attitude and control subsystem. It was decided to attempt to estimate the compressibility of the SDHE data separately for the cases 1) where the attitude of the spacecraft is properly stabilized and 2) where the satellite is in the process of slewing. Figure 6 summarizes the estimated compressibility of the OAO-SDHE data in both the slewing and non-slewing mode. A discussion of some of the items included in Fig. 6 is contained in the remainder of this section. One possible point of confusion concerns the figures given in the columns "Average Number of Bit Required in Compressed Frame," of Fig. 6. In Sec. 3.2 it was decided that all compressed data points be encoded into a 16-bit word consisting of an 8-bit address and an 8-bit magnitude. The fact that the figures in these columns are not, in general, integral multiple of 16-bit results from taking an average over a very large number of frames. In any single compressed SDHE frame there will be an integral number of 16-bit compressed data words.

Data Field	Number of Bits Required in Uncompressed SDHE Frame	Non-Slewing Mode		Slewing Mode	
		Estimated Sample Compression Ratio	Average Number of Bits Required in Compressed Frame	Estimated Sample Compression Ratio	Average Number of Bits Required in Compressed Frame
Frame Sync	26	1.6	16.0	1.6	16.0
ID and Time	26	16.0	1.6	16.0	1.6
Program Code & CMAR	26	1.5	32	1.5	32
Gimbal Data					
Gimbal Address	240	∞	0	∞	0
Commanded M.S.*	96	∞	0	1200	0.16
Commanded L.S.*	96	∞	0	1200	0.16
Error M.S.	96	∞	0	8	24
Error L.S.	96	∞	0	1	192
Bi-Level Data	156	6.7	43	6.7	43
Analog Data	832	25	61.4	15	102.4
TOTAL	1690		154.0		411.32

Bandwidth Compression (Non-Slew) = 11.0

Bandwidth Compression (Slew) = 4.1

Bandwidth Compression (Overall) = 9.26 (based upon 10 percent slewing cycle)

* M.S. = Most Significant 8-bit byte; L.S. = Least Significant 8-bit byte.

Fig. 6 Estimated Compressibility of OAO SDHE Telemetry

3.4.1 Telemetry Control Data

The Telemetry Control Data consists of Words 0, 1 and 2 of the SDHE frame and contains information to synchronize, time tag and identify the data presented in the remainder of the frame. Because most of the fields within this portion of the SDHE frame are highly predictable, the compressibility of the telemetry control section can be estimated more accurately than the following sections of the frame. The compressibility of this data is completely independent of the attitude control status of the spacecraft.

Because of the shorter average length of a compressed SDHE frame it was felt that there was no need for a long frame sync pattern in the compressed data. However, for time tagging and data reconstruction purposes it is necessary to identify the reception of every SDHE frame even if the data portions of the frame are completely redundant. A unique 16-bit word will adequately serve to identify the start of a compressed data frame.

Word 1 contains a 12-bit identification field and a 12-bit spacecraft time field. The ID field is completely redundant. The 12-bit time word would be processed in two data syllables, one of which would contain the 8 least significant bits of time and the other containing the most significant 4 bits along with 4 bits of ID. Since the least significant bit of spacecraft time changes every 15 spacecraft seconds (15.75 actual seconds), the ZOP (using an error tolerance of $K = 1$) will encode a compressed least significant time word once every 10 SDHE frames. A change in the most significant time word will occur only once every 2480 SDHE frame and contributes only an insignificant amount to the overall bandwidth.

Word 1 contains two 8-bit syllables for Program Code and one syllable for the Command Memory Address Register (CMAR). In general, the Program

Code syllables will be non-redundant and will result in two 16-bit compressed data words. The CMAR field will change much less frequently than the SDHE frame rate and will therefore be highly compressible.

3.4.2 Gimbal Data

Words 3 to 26 represent 24 gimbal angle measurements. A "commanded angle" and "error angle" are monitored for both the inner and outer gimbals of each of the six star trackers. The "commanded angle" changes only at the beginning of each slew and remains static until the next slewing operation. Therefore the 12 commanded gimbal angles are almost completely redundant both during the slewing mode and the non-slewing mode.

For the error gimbal angles there will be a very significant difference between the slewing and non-slewing mode. In the non-slewing mode the star trackers will be locked onto stationary targets and only very nominal variations are expected. It is assumed that the error tolerance (K) can be set such that the ZOP data compressor will find these error gimbal angles almost completely redundant. On the other hand, the error gimbal angles will change quite rapidly during a slewing operation. For this case it is assumed that the least significant syllable of the gimbal error angle is completely non-redundant and twelve compressed data points will be produced per SDHE frame. Actually there will probably be some redundancy in this data, but in order to derive a conservative estimate complete non-redundancy will be assumed. However, even during a slew the most significant syllable of the error gimbal angles will possess considerable redundancy. Assuming an average slewing rate of 0.1 degree per second over the entire slew (including settling time) a sample compression ratio of 8 can be achieved.

3.4.3 Bi-Level Data

An estimate of the compressibility of the bi-level data was obtained by observing the frequency of transitions in a group of 20 bi-level sensors present in the OAO-A1 data. Over an extended observation period it was determined that the average probability that a given bi-level sensor would make a transition between any two adjacent sample times was 0.02. Therefore if 8 bi-level sensors are assembled into a pseudo-word and if there is statistical independence between sensors, then the probability (P) that a change in any one of the 8-bit positions will occur between two successive samples of this word is given by

$$P = 1 - (1 - 0.02)^8 = 0.15$$

This figure results in a sample compression ratio of $1/0.15$ or 6.7. In talking with various GSFC personnel concerned with OAO it was learned that the high activity rate on the bi-level sensors observed in the OAO-A1 telemetry was due in part to improper attitude control of the spacecraft and would not necessarily be typical of bi-level data obtained from a future OAO satellite. Nevertheless, a sample compression ratio of only 6.7 was used as a basis for estimating the bi-level compressibility both in the slewing and non-slewing modes.

3.4.4 Analog Data

Since the analog data represents almost exactly half of the total SDHE frame, the compressibility of this portion will strongly influence the overall SDHE compressibility. The analog data is subdivided into two sections: Words 33-52 represent the Operational or Environmental Group, and Words 53-64 represent Analog Group A, B, C or D. There is synchronous subcommutation of each of these groups onto the SDHE frame and thus a complete analog readout occurs once every four frames. Analysis of the instrumentation lists reveals the following subdivision of the uncompressed bandwidth devoted to the analog data:

SENSOR CATEGORY	PERCENT OF UNCOMPRESSED ANALOG BANDWIDTH
Attitude and Control Sensors (including magnetometer data)	24%
Power Supply and Communications System Status Sensors	49%
Thermal Sensors	23%
Pressure and Miscellaneous Sensors	<u>4%</u>
	100%

Although much of the analog data from OAO-A1 was unusable due to equipment malfunction, the analog sensors output which was not adversely affected was analyzed. It was found that an average sample compression ratio of 15 could be achieved without undue impairment to the fidelity of the reconstructed data. Since during the period that these OAO-A1 analog measurements were taken the spacecraft was not properly stabilized, the above sample compression ratio has been taken as the estimate for the slewing mode case. A considerably higher sample compression ratio is expected for the non-slewing mode due to the reduction in activity of the attitude and control sensors and also, to a lesser degree, the thermal sensors. For this case, a sample compression ratio of 25 has been estimated.

3.5 Overall SDHE Compressibility

By combining the weighted estimates of the compressibility of each type of data in the SDHE frame, bandwidth compression ratios for the entire SDHE frame of 11.0 and 4.1 are obtained for the non-slewing and slewing cases, respectively. An overall bandwidth compression ratio of 9.26 was obtained using the assumption that the spacecraft will be actively slewing only 10% of the time.

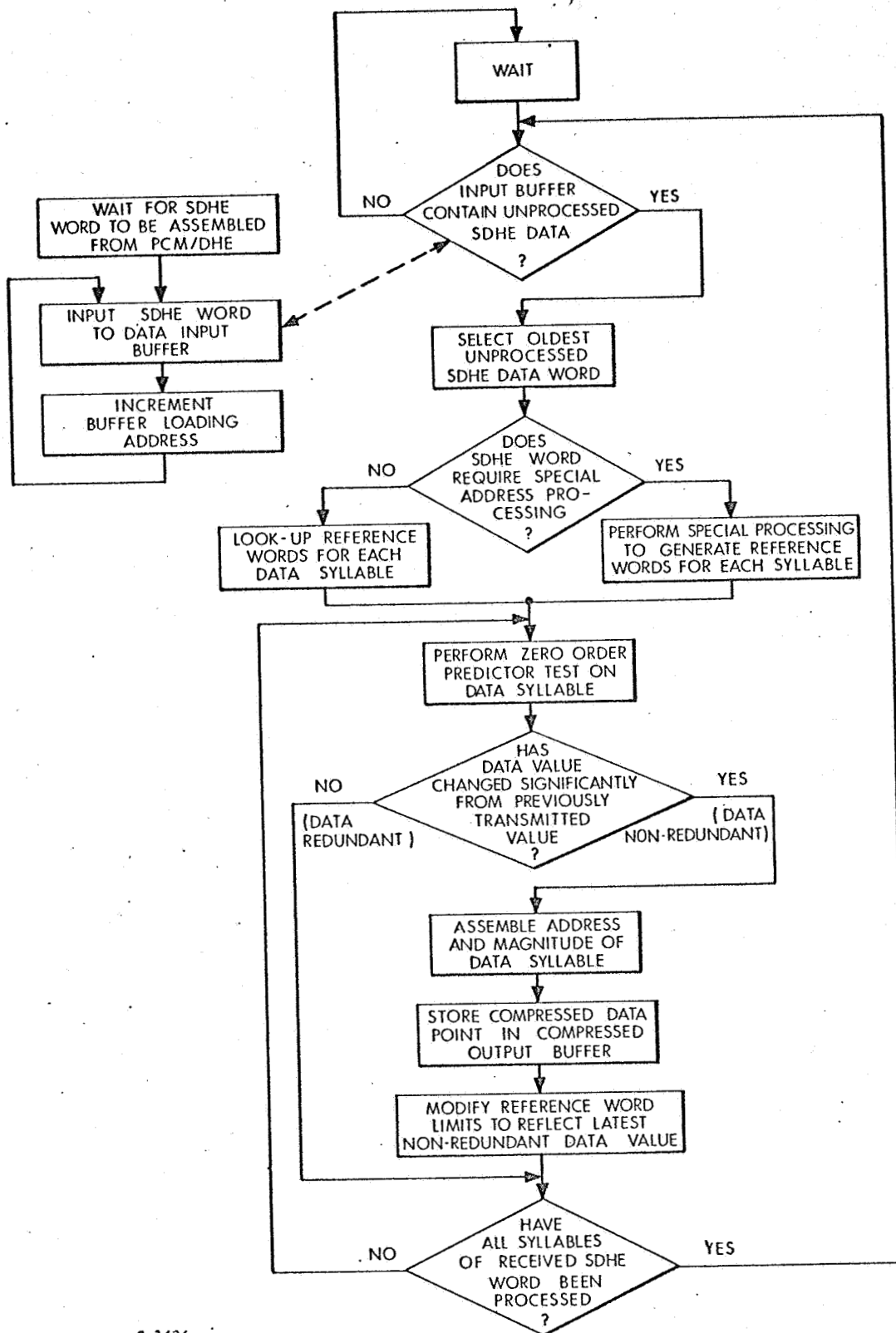
4. PRELIMINARY ANALYSIS OF POSSIBLE SDHE DATA COMPRESSION CONFIGURATIONS

4.1 General

In this section three different equipment configurations will be analyzed to process the SDHE data and to provide an accurate transfer of the compressed data from the remote station to the OAO Control Center at NASA/GSFC. The specific functions which must be performed by this system are the following:

- input OAO SDHE telemetry data from PCM/DHE or digital magnetic tape;
- perform data compression;
- format compressed data in NASCOM compatible blocks;
- perform error detection encoding;
- control data transmission of encoded block;
- receive acknowledgment messages from OAO central;
- perform error detection decoding of acknowledgment messages;
- retransmit blocks received incorrectly at OAO central.

In the first two configurations considered, the AD/ECS-37 performs the data compression function using the ZOP algorithm. To derive an accurate estimate of the ability of the AD/ECS-37 computer to perform the function, it was necessary to flow-chart and efficiently program the inner program loops of the ZOP algorithm. Figure 7 is a flow chart of the normal ZOP processing. The Appendix contains the assembly coding of the most frequently executed loops involved in the SDHE data compression. The purpose of performing this coding was not to produce a finished program but rather to permit a fairly accurate estimate of the processing time involved. No attempt was made to code those sections of the program which would be entered only under very unusual situations although a finished program would have to provide for all contingencies, however rare.



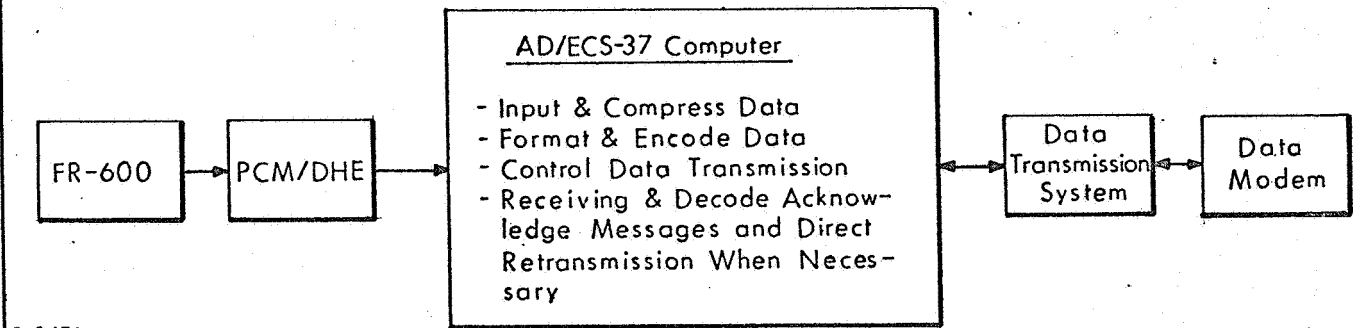
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Fig. 7 Data Processing Required to Input and Compress OAO SDHE Telemetry Data Using Zero Order Predictor (ZOP) Algorithm

For the most commonly traversed sections of the ZOP software algorithm every attempt has been made to produce efficient coding. Undoubtedly further minor improvements can still be made in the coding; however, it is believed that the present coding would perform the ZOP algorithm in a nearly optimum manner for the AD/ECS-37 computer. The estimate of the time required to perform the SDHE data compression is based on the sample coding contained in the Appendix.

4.2 Configuration A

Figure 8 shows the equipment set up and principal characteristics of Configuration A. In this case the SDHE telemetry data which was originally recorded on the FR-600 at the ground station at a 66,688 bits/s rate is played back at a slower speed into the PCM/DHE. The AD/ECS-37 receives the assembled SDHE data words from the PCM/DHE and performs the data compression message formatting, error detection encoding, message queuing, and message transmission control. The playback data rates from the FR-600 are restricted to be equal to the recording rate (66,688 bits/sec) times some negative power of two. The problem then reduces to finding the fastest of these quantized data rates such that the AD/ECS-37 can keep up with the resulting input rate from the PCM/DHE. Figure 8 shows the fraction of the available processing time required to perform the various required functions for an input data rate of 2084 bits/s for the non-slewing case ($\bar{N} = 11.0$) and the slewing case ($\bar{N} = 4.1$). While there is a small amount of estimated reserve capacity in both of these cases, the amount is not sufficient to permit a doubling of the data input rate. Therefore the maximum FR-600 playback rate is limited to 2084 bits/s and at this rate it would take 50 minutes to compress, format, encode and transmit the SDHE telemetry back to GSFC if there were an interval of 100 minutes between SDHE playback interrogations. In addition, this configuration results in only a 12% utilization of the communications circuit to GSFC.



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Fig. 8 Configuration A Characteristics

Functions Performed by AD/ECS-37 Computer

AD/ECS-37 Duty Cycle
 $\bar{N} = 11.0^*$ $\bar{N} = 4.1^*$

Functions Performed by AD/ECS-37 Computer	$\bar{N} = 11.0^*$	$\bar{N} = 4.1^*$
Input SDHE Data at 2084 Bits/s	10.76%	10.76%
Perform Zero-Order Predictor Test (Does Not Include Special Processing on Non-redundant Data)	51.00%	51.00%
Perform Special Processing on Non-redundant Data	3.25%	8.82%
NASCOM Block Formatting	0.39%	1.04%
Error Detection Encoding	3.36%	9.08%
Error Detection Decoding for Acknowledge Messages	3.36%	9.08%
Data Transmission Control (Through Block Buffers)	0.39%	1.04%
Estimated Reserve Capability	27.49%	9.18%
TOTALS	100.00%	100.00%

* The symbol \bar{N} refers to the bandwidth compression ratio.

Maximum SDHE Input Rate: 2×10^4 Bits/s

Time to Compress and Process Entire Playback Message: 50 minutes

Advantages: No Additional Equipment Required

Disadvantages: 1) Lengthy Delay in Sending Data to GSFC
 2) Poor Communications Circuit Utilization (12% Average Duty Cycle)
 3) Lack of Adequate Reserve Capability During Periods of Low SDHE Compressibility

4.3 Configuration B

This configuration is shown in Fig. 9 and is similar to the previous configuration except that the uncompressed SDHE data is received from a digital magnetic tape unit. The generation of the digital magnetic tape containing the uncompressed SDHE data is assumed to be performed by a separate off-line process. Since the transfer of a block of information from the magnetic tape to the AD/ECS-37 is under direct computer control, the computer can conveniently vary the input data rate to adapt to its present workload. In this way, the possibility of buffer overflow is completely eliminated and also this scheme will permit full utilization of the computer's capacity. For an overall bandwidth compression ratio of 9.26, an average bit input rate of 3050 bits/s is believed possible. This would permit the compression and transmission of 100 minutes of recorded SDHE data in a total of 35 minutes.

While this configuration is an improvement over Configuration A in speed and communication circuit utilization, the results are still generally unsatisfactory. In addition, the maintenance of digital magnetic tape units at remote stations might prove to be a serious problem.

4.4 Configuration C

In this configuration, shown in Fig. 10, a special-purpose processor is used to perform the data decommutation and compression. The compressed data points (16 bits) are stored in a self-contained core memory and are inputted to the AD/ECS-37 in blocks of 64 words through the BI buffer. By relieving the AD/ECS-37 of the decommutation and compression functions, more processing time is made available for the computer to perform the NASCOM block formatting, error detection encoding and transmission control.

The special-purpose processor would be designed to input the SDHE data from the PCM/DHE, to identify each data syllable by a decommutation

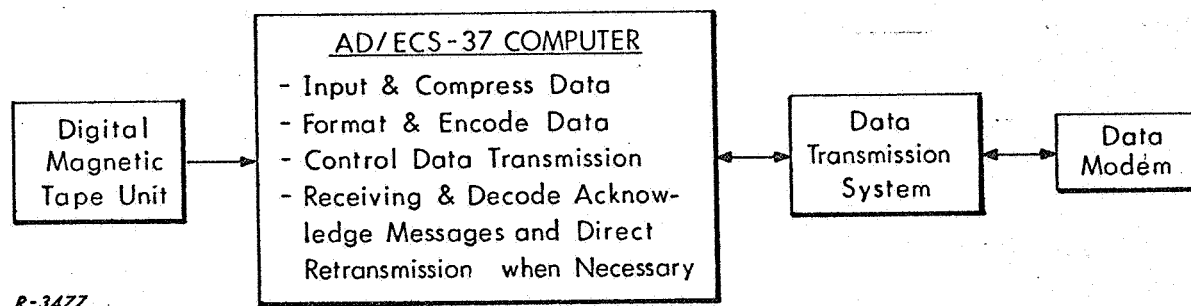


Fig. 9 Configuration B Characteristics

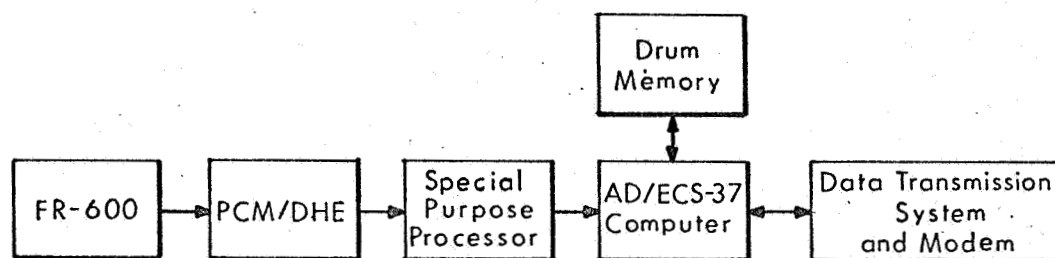
Functions Performed by AD/ECS-37 Computer	AD/ECS-37 Duty Cycle ($\bar{N} = 9.26$)
Input SDHE Data from Digital Magnetic Tape at Average Bit Rate of 3050 Bits/s	4.09%
Perform Zero-Order Predictor Test (Does Not Include Special Processing of Non-redundant Data)	74.54%
Perform Special Processing on Non-redundant Data	5.55%
NASCOM Block Formatting	0.67%
Error Detection Encoding	7.14%
Error Detection Decoding on Acknowledge Messages	7.14%
Data Transmission Control (Through Block Buffers)	0.87%
TOTAL	100.00%

Average SDHE Data Input Rate: 3050 Bits/s

Time to Compress and Process Entire Message: 35 minutes

Advantages: Eliminates any Possibility of Buffer Overflow

Disadvantages: 1) Lengthy Delay in Sending Data to GSFC
 2) Poor Communications Circuit Utilization (17% Average Duty Cycle)
 3) Additional Maintenance and Reliability Problems Associated with Digital Tape Drives



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Fig. 10 Configuration C Characteristics

Functions Performed by Special Purpose Processor

- Input SDHE Data From FR-600 at 16,672 Bits/s
- Decommute SDHE Data
- Perform Zero-order Predictor Test and Compressed Data-point Formatting for Non-redundant Data
- Queue Compressed Data-points for Input to AD/ECS-37 Through BI Buffer

Functions Performed by AD/ECS-37 Computer

- Input Compressed Data-points from Special Purpose Processor Through BI Buffer
- NASCOM Block Formatting
- Error Detection Encoding
- Data Transmission Control

Maximum SDHE Input Data Rate: 16×1042 Bits/s

Time to Compress and Transmit Entire Message: 6 minutes

Advantages: Minimum Transmission Delay to GSFC Efficient Utilization of Communication Circuit

Disadvantages: Special Purpose Processor Required. Approximately 12,000 Words of Drum Memory may be Required for Output Buffering During Periods of Peak Activity

Note: No Drum Memory Required if Input Data Rate Reduced to 8×1042 Bits/s

process and to apply the ZOP algorithm to each data syllable. The processor will contain a core memory which will serve as the reference memory for the ZOP processing as well as temporary buffer storage for the compressed data points. The capability will exist for AD/ECS-37 to load the reference memory in order to change error tolerances on any or all of the SDHE sensors. A recommended set of specifications for the special purpose processor is contained in Appendix B.

Input data rates up to 250,000 data samples per second are well within the state-of-the-art so that the overall data compression and transmission time would be determined solely by the other system constraints. In this case the two constraints which limit the maximum input data rate are: 1) the information bandwidth limitation of the communication link to GSFC (using the NASCOM 600-bit format) of 1920 bits/sec, and 2) the processing capability of the AD/ECS-37 to format, encode and provide transmission control. If the FR-600 is set to read the SDHE data into the PCM/DHE at 1/4 of the rate at which it was dumped, the resulting input rate of 16,672 bits/sec to the special-purpose processor will permit 100 minutes of SDHE data to be processed and transmitted in 6-1/4 minutes.

Because of the fast input rate achievable with this configuration, the possibility exists for a sizable buffering problem within the AD/ECS-37 during periods of low compressibility. For instance, assume that the OAO satellite requires three minutes to perform a slewing operation and that during this entire period the average bandwidth compression ratio is 4.1. If the FR-600 is running at a 16,672 bits/sec rate, the average output rate from the special-purpose processor will be $16,672/4.1$ or 4060 bits/sec. However, since the communications link can only accept 1920 information bits/sec., the AD/ECS-37 must provide for a net buffer increase of $4060-1920$ or 2140 bits/sec for the entire three-minute period. At the end of this period the amount of data to be buffered will increase to a total of 12,060 AD/ECS-37 words even assuming that two.

16-bit compressed data points are stored per word. This buffering requirement exceeds the capacity of the main computer memory but could be contained in the 32,768 words of drum memory. On the other hand, a reduction of the FR-600 input rate to 8,336 bits/s would permit the buffering to be handled with a core memory although the total time to compress and transmit the SDHE data would be increased to 12-1/2 minutes by this method.

5. SELECTED DATA TRANSMISSION CONFIGURATION

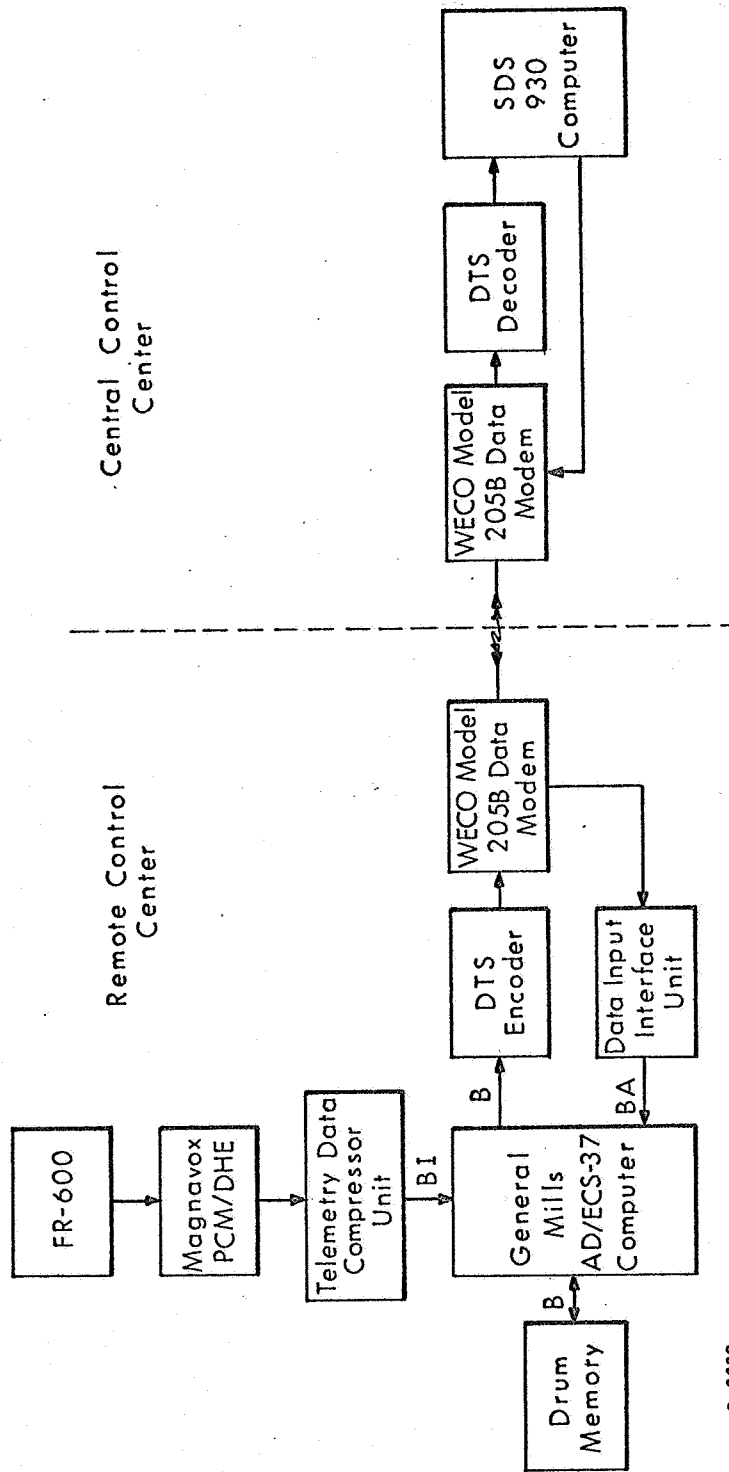
5.1 General

The configurations discussed in the preceding section were considered only on the basis of their ability to compress and transmit playback SDHE data from remote stations back to the OAO Control Center. In addition to the playback SDHE data, there is a need for transmitting many other types of data between the remote stations and the OAO Control Center. It would be highly desirable if the compressed playback SDHE data could be handled in the same manner as other message types, thus eliminating the necessity for special communications equipment or interfaces.

The anticipated means of communication between the OAO remote stations and the OAO Control Center are shown in Fig. 11. In the remainder of this section the input/output capability of the existing communication system will be described in more detail with particular emphasis on the problems the transmission of compressed playback SDHE telemetry data.

5.2 AD/ECS-37 Computer Output to Communication Circuit

All data transmitted from the AD/ECS-37 computer at a remote site to the OAO Control Center will pass through a Data Transmission System (DTS) encoder and a Western Electric Model 205B Data Modem. The DTS encoder performs the function of accepting an asynchronous data input at rates up to 1792 bits/s and outputting a synchronous 2400 bit/s stream to the data modem. The data modem is capable of both transmitting and receiving data at a 2400 bit/s rate. If the DTS input rate is less than 1792 bits/s, the DTS will insert "filler" bits to take up the extra space.



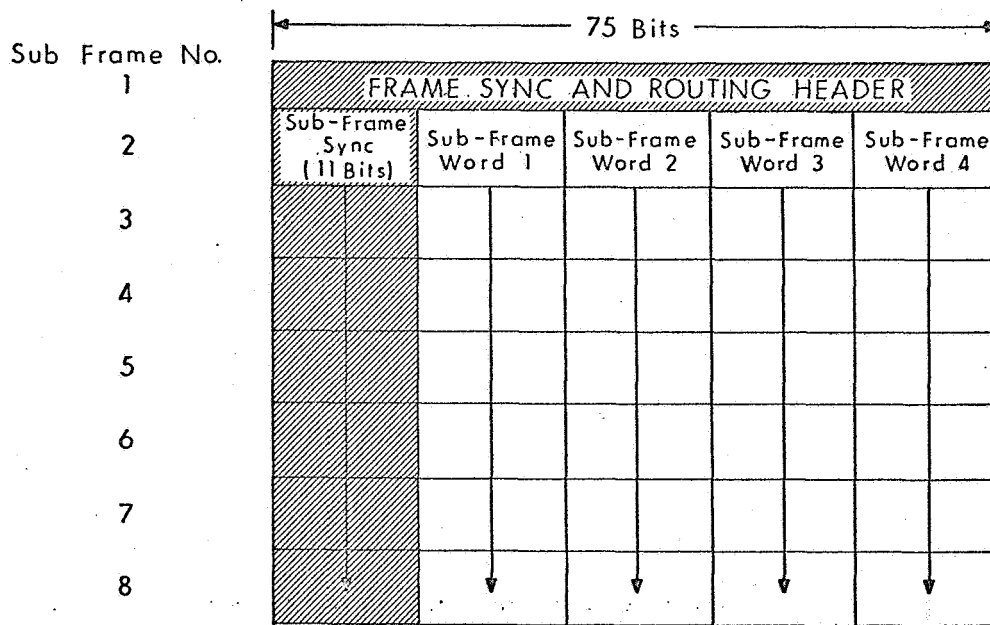
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Fig. 11 OAO Data Transmission Configuration

5.2.1 Message Formats

DTS Block Formats

The DTS encoder also formats the incoming data into 600 bit frames and inserts routing header and synchronization bits as is shown in Fig. 12. Each 600 bit frame is subdivided into eight 75 bits subframes. Subframe No. 1 consists entirely of frame sync and routing header data generated by the DTS. Subframes 2 through 8 contain an 11 bit subframe sync pattern and four 16 bit data words. When the formatted 600 bit block is received back at the OAO Control Center, the DTS decoder will strip off the entire Subframe No. 1 and the 11 bit sync pattern on Subframes 2 through 8, and will output only the data section of the message.



DTS Encoder Inserts Formatting Data Into Cross-Hatched Fields

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Fig. 12 DTS Message Format

Data Block Format

In addition to the formatting performed by the DTS system, an additional level of formatting and coding is provided in the data section. Unlike the DTS blocks, these data blocks may be of variable length from 128 bits to 1024 bits. Each data block consists of between 2 to 16 frames of 64 bits each. The format⁵ of these data blocks is shown below.

<u>Frame Number</u>	<u>Bit Positions</u>	<u>Contents</u>
1	1-16	Synchronization Pattern (1110101110010000)
1	17-31	Block Sequence Number
1	32	Sentinel Bit (Set for Last Block)
1	33-48	File ID
1	49-64	Number of 16 Bit Words (NW) in Block $8 \leq NW \leq 64$
2 thru $\frac{NW}{4} - 1$	1-64	Four 16 Bit Data Words
$\frac{NW}{4}$	1-32	Two 16 Bit Data Words
$\frac{NW}{4}$	33-42	Unused
$\frac{NW}{4}$	43-64	Error Detection Checkbits

The error detection checkbits are generated such that the resulting block is properly encoded in a cyclic block. The generating polynomial will be of 22 order.

In the above format the first frame and the second half of the last frame are taken up with control and synchronization information. To reduce the proportion of the noninformation fields in the overall format it is desirable to format the data into maximum length blocks of 1024 bits. However, a conflicting factor which must be considered is the effect of transmission errors.

Since longer blocks have a greater probability of containing a transmission error, and therefore requiring a retransmission, the optimum block length must strike a compromise between these two factors. An analysis of the optimum block length is contained in Appendix C and reveals that a block length of 1024 bits is optimum based upon the existing format constraints.

5.2.2 AD/ECS-37 Interface to DTS Encoder

The AD/ECS-37 computer will output data to the DTS encoder via the B buffer in 16 bit parallel words. The sequence used in transferring a 16 bit data word to the DTS is the following:

- (1) The AD/ECS-37 loads the 16 bit data word in right adjusted format into the B buffer.
- (2) The AD/ECS-37 executes an External Machine command which directs the DTS to read the current contents of the B buffer.
- (3) The DTS encoder will input the 16 bit data word and will generate the proper control signals to disconnect the DTS encoder from the B buffer. This action will cause a "B Busy" signal to be generated which will result in a computer interrupt signifying that a new data word may be loaded into B and the cycle repeated.

The AD/ECS-37 computer must reload B and initiate another External Machine command to the DTS encoder within $6\frac{2}{3}$ ms after receiving the "B Busy" interrupt. If the computer does not respond within this time period, the DTS encoder may generate a "filler" frame rather than a "data" frame.

5.3 Communications Circuit Input to AD/ECS-37

5.3.1 General

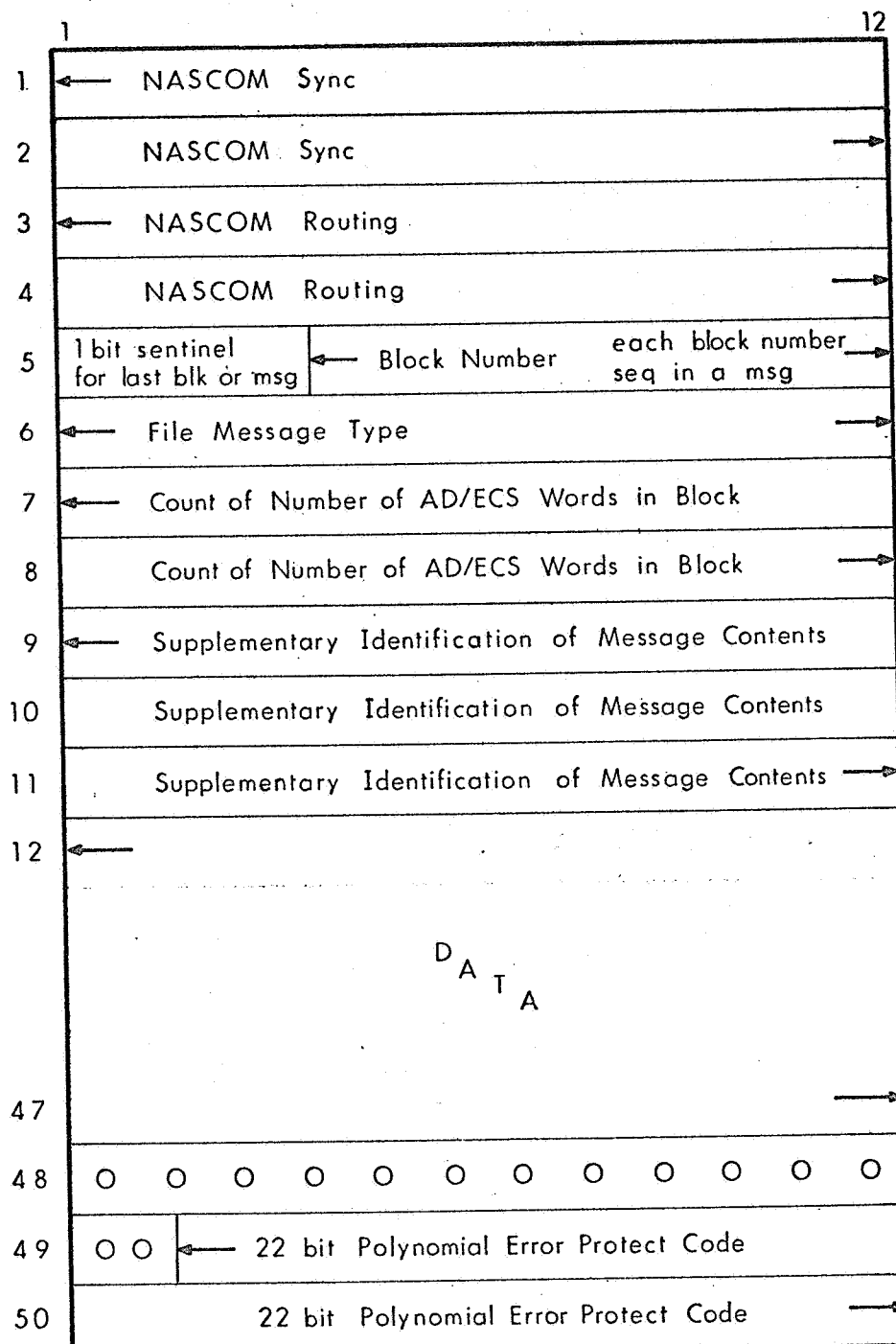
The Remote Control Centers receive messages from the OAO Central Control Center via a 2400 bit/s communications circuit driven by Western Electric 205B data modem.

5.3.2 Message Format

All messages from OAO Central Control Center to a Remote Control Center are formatted into a 600 bit block. The format⁵ of this block is shown in Fig. 13. Of the fifty 12 bit words in the block, fourteen words are devoted to non-data fields. While many different types of messages will be required for the various OAO ground support functions, the only message types directly related to data compression are the "Acknowledge Message" and the "Retransmission Request Message". Word 6 of the block format shown in Fig. 13 identifies the message type and Words 9, 10 and 11 contain supplemental information concerning the message type.

5.3.3 AD/ECS-37 Interface to Communication Circuit Input

An interface unit will be designed to transfer data between the Western Electric 205B data modem and the AD/ECS-37 computer. This interface unit will examine the incoming bit stream and will recognize the presence of the 24 bit frame sync pattern when it occurs. After the frame sync pattern has been received, the interface unit will transfer the next 576 bits of the current block into the BI buffer. The data will be assembled in BI as sixteen 36 bit words. Following the loading of the 576 bits the interface unit will disconnect itself from the BI buffer and generate a "EM Busy" signal which will trigger Interrupt Level 6 of the AD/ECS-37 computer. The AD/ECS-37 will respond to the interrupt within 10 ms by storing BI and initiating another command for the input of a block into BI.



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Fig. 13 Central Control Station to Remote Control Station
Message Format

6. PROPOSED PLAYBACK SDHE DATA COMPRESSION PROCEDURE

6.1 General

In Sec. 4.4 a configuration was discussed in which the data transmission proceeded concurrently with the data compression operation. This resulted in the most efficient operation from the standpoint of minimizing the time required to get the compressed SDHE data back to the OAO Central Control Station. Because of timing problems with the peripheral equipment to the AD/ECS-37, it is not feasible to implement this procedure exactly as outlined in Sec. 4.4. Whenever a read or write instruction to the drum memory is given, the entire computer is tied up for the entire period necessary to find the starting point on the drum and to perform the required data transfer. Under worst case conditions, as much as 35 ms will be required merely to find the starting point. During this period the computer will not respond to any received interrupts. With the present data transmission system it is desirable* to guarantee a response to the DTS encoder within $6\frac{2}{3}$ ms of a randomly occurring interrupt and it is mandatory that the computer respond within 10 ms to an "EM Busy" interrupt signifying a message input request via BI. Since any data transfer command to the drum is likely to result in missed interrupts, the procedure must be modified to reflect these timing problems.

6.2 Phase I - SDHE Data Compression and Storage

The proposed approach consists of two serial phases. In the first phase the FR-600 is played back at 32×1042 bit/s rate through the Magnavox PCM/DHE and into a special purpose data compressor. The compressed SDHE data is then assembled in blocks of 128 compressed 16 bit data points and

* The reason that it is not mandatory that the computer respond within $6\frac{2}{3}$ ms to a DTS encoder interrupt (B Busy) is that the DTS will insert an invalid 16 bit word (all zero bits) if a new word from the computer is not received in time. The SDS-930 could be easily programmed to disregard any received word with an all zero pattern.

inputted to the AD/ECS-37 core memory via the BI buffer. After a sufficient amount of compressed data has been assembled within the core memory, the AD/ECS-37 will transfer this data to the drum. This will continue until the entire SDHE playback message has been compressed and stored on the drum. Note that the data transfers between the drum and core can proceed concurrently with the compressed data input since the data compressor has sufficient buffering capacity to allow an interrupt response time of as much as 65 ms.

6.3 Phase II - Data Transmission and Verification

During the second phase of the operation the compressed SDHE data is transferred back into core and the AD/ECS-37 encodes the data in the format described in "Data Block Format" on page 29, generates the error detection checkbits, and initiates the transfer of the formatted and encoded data via the DTS system. During this phase the AD/ECS-37 must also receive, decode and respond to "Acknowledge" and "Retransmission Requests" messages.

6.4 Processing Time Estimate with Proposed Configuration and Procedure

By performing the data compression and storage phase separately from the data transmission and verification phase, the possibility of overloading the capacity of the AD/ECS-37 computer at the remote site is totally eliminated. Estimates of the time required to perform the two phases of this operation will be obtained in this section.

A timing analysis of the processing required by the computer to receive the compressed SDHE data from the data compressor and store this data onto drum memory reveals that the recorded SDHE data may be played into the Magnavox PCM/DHE at a rate of 33,344 bits/s (equal to 32 times the onboard recording rate of 1042 bits/s). Assuming a time interval of 100 minutes between successive onboard tape dumps, the Phase I processing time would be three minutes.

A number of assumptions are required in order to estimate the processing time required for Phase II. These assumptions include the following:

- (1) The average bandwidth compression ratio over the entire SDHE message is assumed to be 9.26 (see Sec. 3.5).
- (2) The SDHE compressed data will be encoded into 1024 bit blocks exclusive of the additional bits inserted by the DTS encoder.
- (3) The error distribution over the communication channel is assumed to be that of a binary symmetric channel with bit error rate equal to 1.77×10^{-5} (see Appendix C).
- (4) An average of a 0.5 second delay occurs between the transmission of a block and the receipt of an "Acknowledge" or "Retransmission Request" message.
- (5) The total information bandwidth of the communication circuit to OAO Central Control Station is 1792 bits/s. (The reduction from 2400 bits/s is due to the additional synchronization and routing data inserted by the DTS encoder and subsequently removed by the DTS decoder.)

Based on the above assumptions the time required to transmit the entire compressed SDHE message over the communication system is eight minutes. Of this time, only 20 seconds are required to handle the retransmission request. Thus, the total estimated time for both Phases I and II is eleven minutes.

In Sec. 4.4 the processing time required to compress and transmit the entire SDHE message using configuration C was found to be $6\frac{1}{4}$ minutes. This estimate, however, did not include the effects of: (a) the reduced information bandwidth of the communications channel due to the DTS formatting; and (b) the additional time required for the retransmission of blocks originally received in error. The effect of the decreased bandwidth adds 85 seconds to the processing time and the retransmission processing adds 20 seconds. Adding those two

factors to the previously obtained estimate of $6\frac{1}{4}$ minutes results in a revised estimate of eight minutes. Thus, the only difference between the currently proposed approach and the approach discussed in Sec. 4.4 (Configuration C) is the separate processing of the data compression and data transmission phases.

Without a major redesign of the peripheral equipment and interfaces associated with the AD/ECS-37 computer (drum, DTS interface and modem input interface) it appears unfeasible to eliminate the previously discussed timing problem. Therefore, the partitioning of the processing into two sequential phases and the resulting increase of three minutes in the total processing time appears unavoidable.

7. RECONSTRUCTION OF SDHE COMPRESSED DATA AT OAO CONTROL CENTER

Each compressed data point is received by the SDS-930 at the OAO Control Center as a 16 bit word consisting of an 8 bit address and an 8 bit magnitude. Because of the subcommutation scheme of the SDHE format, there actually exists a total of 381 different sensors or pseudo-sensors monitored by the SDHE telemetry subsystem. However, only 195 sensors or pseudo-sensors are monitored on any single SDHE frame. The particular sensor set monitored on any given SDHE frame can be determined by examining the Program Code field of Word 2 and the most significant 3 bit field of Word 29. The subcommutation identification contained in those fields are encoded into a compressed data word. The 8 bit address field associated with each data point merely indicates the position of the 8 bit syllable within the current frame and the previously received subcommutation information within the same frame permits the unambiguous identification of all sensors.

For the purpose of data reconstruction, the SDHE format can be divided into the following seven categories:

<u>Item</u>	<u>Main Frame Word Number</u>	<u>Data Content</u>	<u>Comments</u>
1	0 to 2	Telemetry Control	Not Subcommutated
2	3 to 26	Gimbal Angle Data	Not Subcommutated
3	26A, 27 to 29	Star Tracker Status* (26A) & Bi-level Words 1, 2 and 3	Not Subcommutated
4	30	Bi-level Word 4	Subcommutated to Five Levels
5	31 & 32	Bi-level Words 5 - 6	Subcommutated to Two Levels

(continued)

* The Star Tracker Status Word designated Main Frame Word 26A is actually a pseudo-word formed by the data compression unit from twelve separate 2 bit fields contained in each even main frame word from MF4 to MF26.

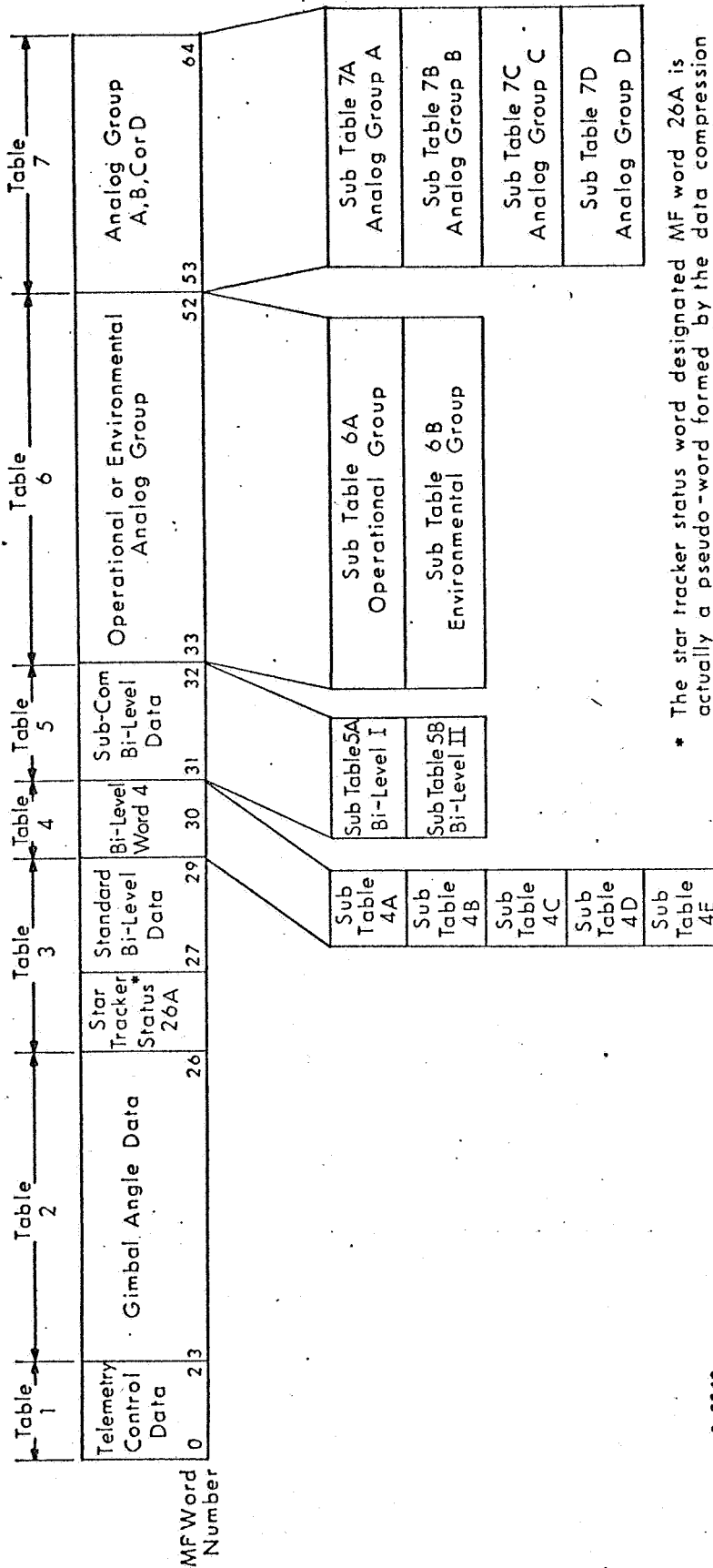
<u>Item</u>	<u>Main Frame Word Number</u>	<u>Data Content</u>	<u>Comments</u>
6	33 to 52	Operational or Environmental Analog Group	Subcommutated to Two Levels
7	53 to 64	A, B, C, or D Analog Group	Subcommutated to Four Levels

The proposed method of SDHE data reconstruction is to maintain seven separate tables within the core memory of the SDS-930 computer associated with each category. Separate subtables will also be maintained for each level of subcommutation contained within the category. Figure 14 is a diagram of the proposed SDHE Data Reconstruction Tables.

At the start of the SDHE data compression operation of a particular pass, the reference memory of the data compressor unit will be loaded with commands which will force the output of the first readout of each sensor or pseudo-sensor. When the data associated with this forced first value readout is received by the SDS-930, it will be stored in the appropriate table storage area.

Following this forced readout, all subsequent sensor values will be processed by the data compressor in the normal manner and will result in a compressed data word output only if the data value was found to be nonredundant. As compressed data words are received by the SDS-930, the appropriate table associated with the sensor will be updated. In this way the seven tables will always contain a replica of the current state of the sensors monitored on the SDHE telemetry within the preset tolerance limits established for each sensor.

After the SDHE Data Reconstruction Tables have been updated with all the compressed data from a given frame of SDHE data, the data reconstruction program will construct a control word which will indicate to the SDHE analysis and display programs precisely which tables and subtables have been updated by the current frame of SDHE data. One possible format for the control word is shown below.



* The star tracker status word designated MF word 26A is actually a pseudo-word formed by the data compression unit from 12 separate 2-bit fields in each even MF word from MF4 to MF26.

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Fig. 14 SDHE Data Reconstruction Tables

Bit Number	BLANK	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
---------------	-------	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Bits	0 - 9	Blank
Bits	10	Table 1 Update *
Bit	11	Table 2 Update
Bit	12	Table 3 Update
Bit	13	Table 4 Update
Bits	14 - 16	Subcom ID for Table 4
Bit	17	Table 5 Update
Bit	18	Subcom ID for Table 5
Bit	19	Table 6 Update
Bit	20	Subcom ID for Table 6
Bit	21	Table 7 Update
Bits	22, 23	Subcom ID for Table 7

* A "1" bit in this position indicates that a change has been made somewhere in the table as a result of nonredundant data received within the current SDHE frame.

8. DATA COMPRESSION DEMONSTRATION

A demonstration of telemetry data compression was performed by ADCOM, Inc. at the OAO Control Center (Building 14 of NASA/GSFC) on June 28 - 29, 1967. This was a company sponsored effort not charged to any NASA contract; however, since some of the results are pertinent to the present study, they are included in this report.

The configuration used in this demonstration is shown in Fig. 15. Except for the data compression unit and the associated interface equipment, the configuration is a standard portion of the OAO Ground Operations Equipment complex available at all primary OAO sites. Figures 16 and 17 are pictures of the DT-110 data compression unit which was supplied by ADCOM for this demonstration.

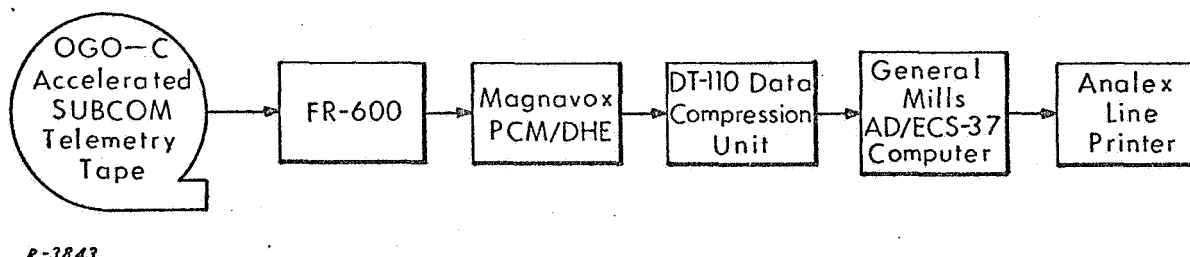
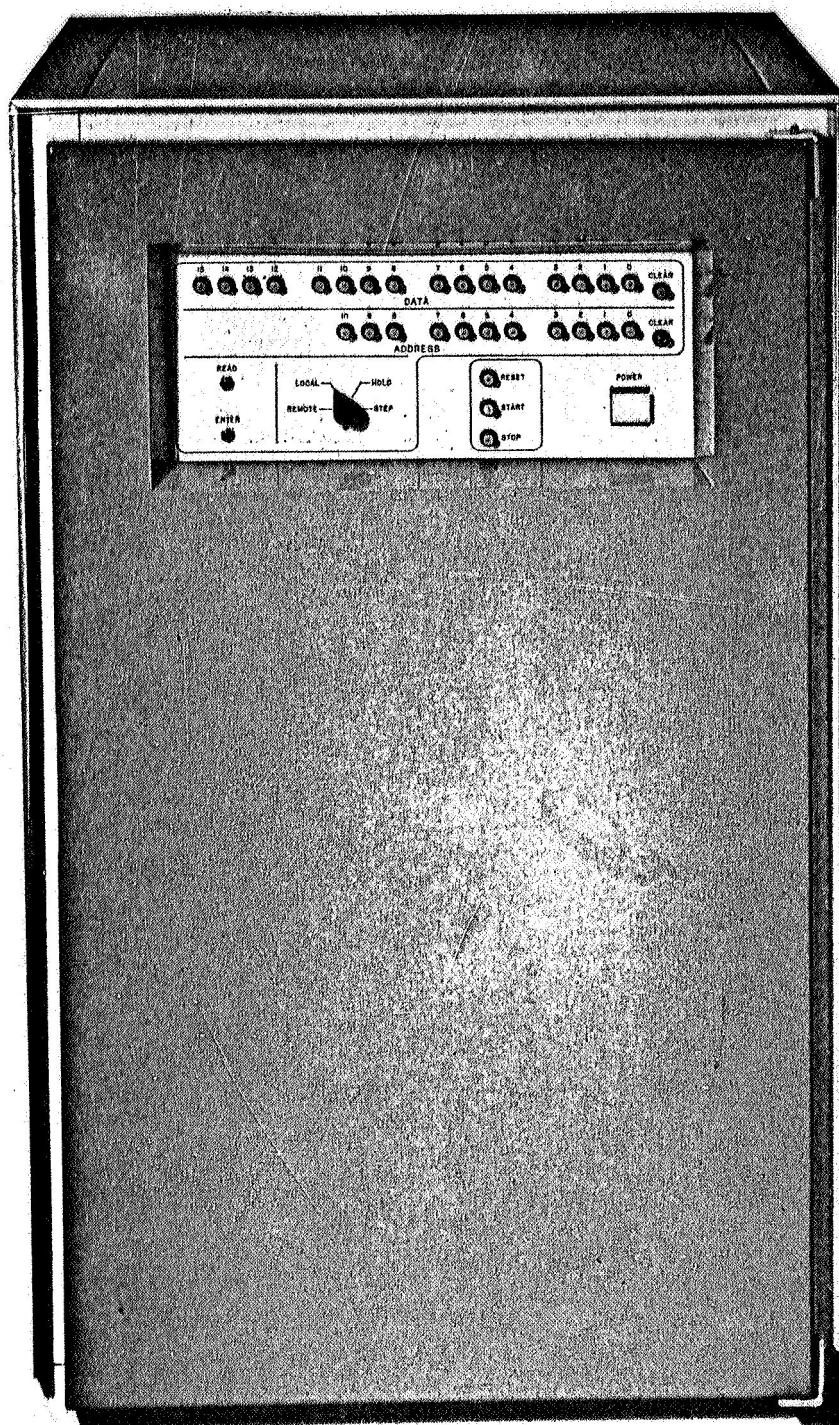


Fig. 15 Data Compression Demonstration Configuration

The analog tape used in this demonstration contained actual accelerated subcom telemetry data recorded at a 64,000 bit/s rate from the OGO-C satellite. There were two reasons for using OGO data for this demonstration. First, the OGO accelerated subcom format does not contain any subcommutation and therefore the Magnavox PCM/DHE was capable of fully decommutating this data. The other reason was that sections of this data were known to be very active and were thought to be a worst case test for data compression.



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Fig. 16 Front View of DT-110

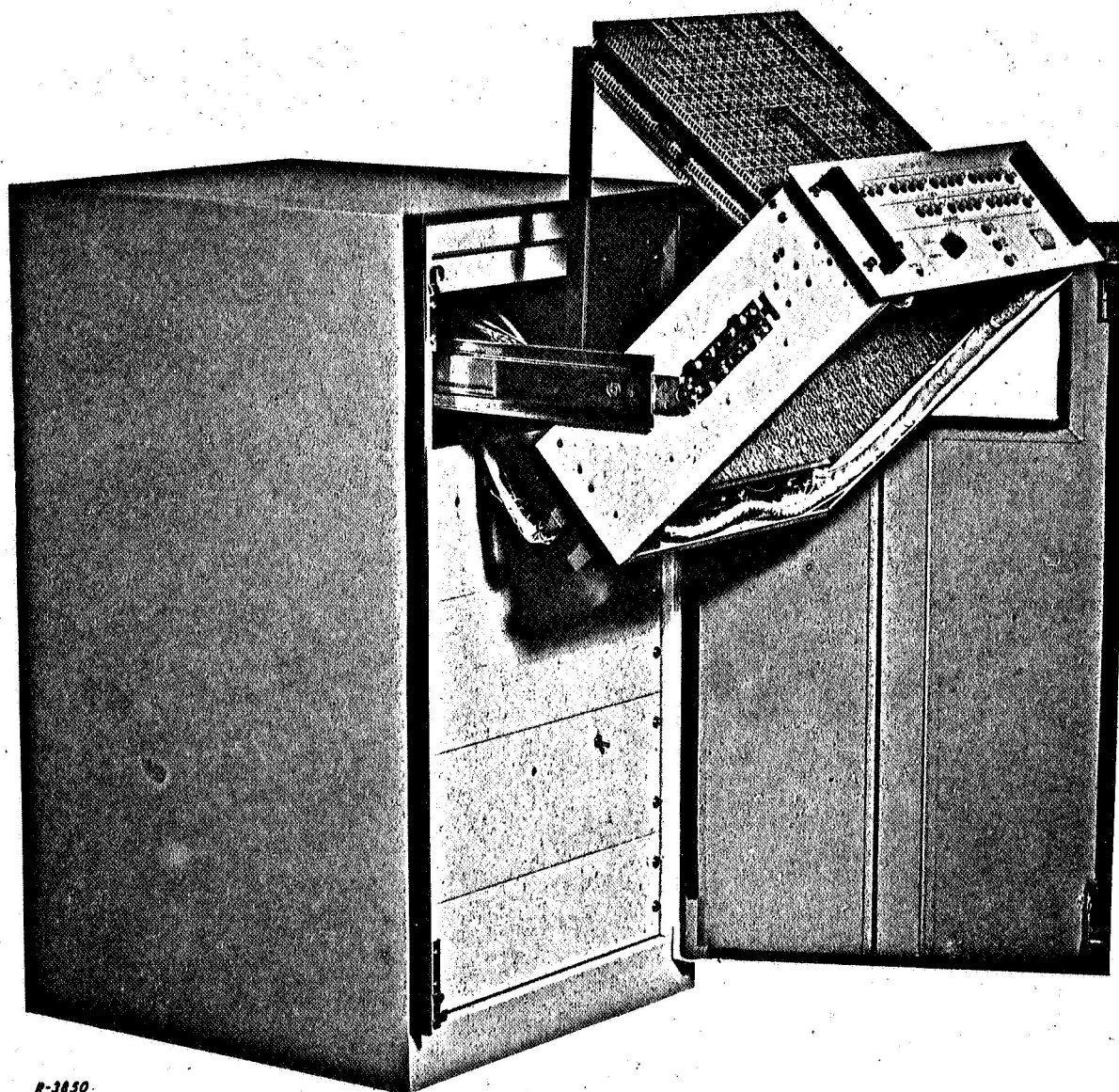


Fig. 17 DT-110 Shown with Drawer Extended

A computer program was written for the AD/ECS-37 computer to output any ten selected telemetry channels onto the line printer. The computer also calculated the individual bandwidth compression ratios of each of the ten selected channels as well as the composite bandwidth reduction ratio for all selected channels. Figures 18 and 19 show the line printer listing for a fairly active segment of data. The sensors monitored on the ten data channels are as follows.

<u>Channel</u>	
1	Accumulated Time (seconds)*
2	Battery No. 1 Current
3	Reaction Wheel ON-OFF
4	Pitch Error (degrees)
5	Gas Control Valves 1, 2, 5
6	Yaw Wheel Tack (rpm)
7	Pitch Rate Gyro
8	Transmitting EG Status
9	Roll Error (degrees)
10	Array Shaft Angle (sine)

During this run the DT-110 was programmed to use a Zero-Order Predictor (ZOP) algorithm on each of these channels with a tolerance value (K) of two.

Another data compression run was made using a section of data obtained after the OGO-C satellite had lost attitude control and was tumbling. A set of ten channels concerned primarily with attitude error signals were selected for the data compression output listing. The results from this run are shown in Figs. 20 and 21. In this case, the ZOP algorithm was used with a tolerance (K) of six for each channel. By monitoring the attitude and control

* This channel should increase in a monotonic manner; however, visual examination of the strip chart from this channel revealed that the telemetry data was actually skipping around as shown in this printout.

COMPRESSED DATA OUTPUT PROGRAM

COMMENTS -- OGO-C DATA INPUT TO DT-110 AT 4000 BITS PER SEC.

START TIME--DAY 134, 17H 23M 56S

TIME	FRAME	1	2	3	4	5	6	7	8	9	10
LAST VALUE											
0											
1	207	9	88	127	8	106	42	56	76	60	
5									74		
18	200										
21									72		
31									62		
32									60		
33									57		
34									62		
35									59		
36									57		
44									47		
56									57		
57				8							
64										44	
65										60	
67									47		
71	77					88	138	14			
72	186		158	95					203	15	
74	200		88	127		107	42	56	47	60	
75						105					
77									57		
79						107					
81						105			59		
84				122							
85				126					61		
86				108							
87				108		107			63		
88				95							
89	108		172	170		184	28	156	155	30	
91	200		88	47		107	42	56	58	60	
92				43							
93				46		105					
94				30		107					
95				27					60		
96				29		105					
97				14							
98				12							
99				13		107					
100				8							
101			121			105			62		
102			121			107					
103			123								
104						105			72		
110						107			74		
112						105					
113						107					
114						105					
118						107					
120						105					
121	201										
126						107					
128						105					
129						107					

Fig. 18 Compressed Data Listing (Fairly Active Telemetry Data)

COMPRESSED DATA OUTPUT PROGRAM

DATA COMPRESSION SUMMARY

OVERALL BW COMPRESSION RATIO (INCLUDING FIRST ^{READING} ~~RFZFYVTZ~~) = 08.09

OVERALL BW COMPRESSION RATIO (EXCLUDING FIRST READING) = 08.27

BANDWIDTH COMPRESSION RATIO BY CHANNEL

	1	2	3	4	5	6	7	8	9	10
WITH										
FIRST	26.59	≥100.	21.90	02.90	≥100.	02.01	53.19	41.37	04.27	33.84
POINT										

Fig. 19 Data Compression Summary Printout Associated with Data Shown In Fig. 18

COMPRESSED DATA OUTPUT PROGRAM

DATA COMPRESSION SUMMARY

OVERALL BW COMPRESSION RATIO (INCLUDING FIRST ^{READING} ~~RFZFYVTZ~~) = 02.49

OVERALL BW COMPRESSION RATIO (EXCLUDING FIRST READING) = 02.50

BANDWIDTH COMPRESSION RATIO BY CHANNEL

	1	2	3	4	5	6	7	8	9	10
WITH										
FIRST	00.95	01.01	05.96	06.14	11.28	06.14	02.80	02.39	02.72	03.90
POINT										

Fig. 21 Data Compression Summary Printout Associated with Data Shown In Fig. 20

COMPRESSED DATA OUTPUT PROGRAM

COMMENTS -- OGO-C DATA INPUT TO DT-110 AT 4000 BITS PER SEC.

START TIME--DAY 134, 17H 23M 56S

TIME FRAME	1	2	3	4	5	6	7	8	9	10
LAST VALUE										
1	118	82	22	109	3	3	10	10	34	47
2		98								
3		114								
6	112									
7	100									53
8	86									
9	72								40	
10	55						49			
11	38	106								
12	25	92								
13	10	77	28				119		90	102
14	0	61	35							
15		45								
16		28					80			
17		14								
18		0						80		
20	15						10			
21	31							120		
22	48									
23	67			101						
24	85	8		109						
25	99	24						49		
26	115	43	15							
27		62	31	45						
28	121	80		109				10		
29		97								
30		111								
31		119								
34	111		12						97	
35	100		28						103	
36	85									
37	71								109	
38	54	108					49			
39	37	94								
40	23	79								
41	10	63			130		120			
42	0	46			2				115	
43		31								
44		14					84			
45		3				130		80		
46						2				
48	15						10			
49	48							119	121	
51	68		22							
52	86	22						49		
53	100	40								
54	116	60								
55		78								
56		94						10		
57		111							127	96
58		117								
62	110									
63	99									
64	85									

Fig. 20 Compressed Data Listing of Attitude and Control Sensors While OGO-C Spacecraft Was Tumbling

sensors during a period where the spacecraft is in an unstabilized condition we obtain what is probably the most highly nonredundant data that would be encountered on any spacecraft mission and therefore represents a worst case situation from the standpoint of data compression. Even under these extremely adverse conditions a composite bandwidth reduction ratio of 2.5 was obtained.

9. RECOMMENDATIONS AND CONCLUSIONS

This study has investigated the estimated compressibility of the OAO SDHE telemetry data as well as the operational procedures, equipment constraints and message formats applicable to the data transmission circuits between OAO Remote Control Centers and the OAO Central Control Station at GSFC. Based upon this study and the practical experience gained during the data compression demonstration it is concluded that data compression can significantly reduce the time required to transmit playback SDHE data from a remote site to GSFC. Assuming 100 minutes between successive SDHE playback commands, the entire SDHE message can be compressed, transmitted, and reconstructed at NASA/GSFC in an estimated eleven minutes using the configuration and procedure described in Sec. 5. If the SDHE data is not compressed at the remote site, 65 minutes would be required for the transmission of the message to NASA/GSFC.

By making the OAO back orbit data available to the OAO project personnel at GSFC in a timely manner, incipient spacecraft problems may be spotted and corrected before they reach critical proportions. This should not only prolong the life of the OAO spacecraft, but also allow more efficient operation and scheduling of the experiments.

REFERENCES

1. Lockheed Missile and Space Company, Final Report for "PCM Telemetry Data Compression Study," Phase I, by Bechtold, Medlin and Weber, NAS5-9729, Sunnyvale, California, October 1965.
2. Lockheed Missile and Space Company, Final Report for "PCM Telemetry Data Compression Study," Phase II, by Bjorn, Friccero and Medlin, NAS5-9729, Sunnyvale, California, January 1967.
3. C. A. Andrews, et al., "Adaptive Data Compression," Proc. IEEE, Vol. 55, No. 3, pp 267-277, March 1967.
4. ADCOM, Inc., "Study of Data Transmission Systems," Phase I, NAS5-10503, Palo Alto, California, March 1967.
5. G. A. Hall, Memorandum Entitled, "SDS-930 and AD/ECS Interface Using HSL," Dated 22 June, 1967.
6. W. B. Dickinson, D. C. Stern and T. C. Wollaston, "Preliminary Performance Analysis of High Speed Digital Data Circuits in the NASCOM Network," NASA/Goddard Report No. X-576-67-264, June 1967.

Appendix A

ASSEMBLY CODING FOR AD/ECS-37 TO PERFORM MOST
FREQUENTLY EXECUTED PORTIONS OF ZOP DATA
COMPRESSION PROCESSING

NOTE: This coding was performed for the purpose of estimating the processing time required for compressing SDHE data using the AD/ECS-37. It is not intended as an operational program.

<u>LOC.</u>	<u>OP.</u>	<u>ADDR.</u>	<u>INC.</u>	<u>COMMENTS</u>
C	PROGRAM TO STORE ASSEMBLED DATA			
C	WORDS FROM PCM/DHE IN A QUEUE			
0003	RET	PCMXIT		Interrupt Trap
	JPL	PCMIN		Processor Linkage
PCMIN	STA	SAVEAP		Save A and
	STR	SAVERP		R Registers
	SBA	A		Store BA in A
	EXM	0730		Command Next PCM/DHE to RA Transfer
BUFSTR	BRG	BUFSTR		
	STR	(0000)		Store Input Word from PCM/DHE
	ADD	ONE		ONE = +000 000 000 001
	STR	BUFSTR		
	SUB	BUFLIM		
	NJP	BUFA		Jump if not end of Buffer
	BRG	BUFKA		BUFKA = BRG BUFSTR STR BUFFER
	STA	BUFSTR		
BUFA	BRG	SAVERP		Restore A
PCMXIT	BRG	SAVEAR		and R Registers
	RJP	(0000)		Return to Main Program
C	DATA COMPRESSION PROCESSING			
C	LINKAGE WITHIN MAIN PROGRAM			
	:			Main Program Processing
	RET	ZOP		Perform ZOP Processing
	JPL	ZOP		on Next SDHE Word in Buffer
	:			Continue with Main Program

<u>LOC.</u>	<u>OP.</u>	<u>ADDR.</u>	<u>INC.</u>	<u>COMMENTS</u>
C	ZOP DATA COMPRESSION PROCESSING			
ZOP	JPL	ZOP	1	Linkage for
	JPL	0000		ZOP Subroutine
	BRG	BUFSTR		
	SUB	NXTWRD		
	AND	ZOPKA		(ZOPKA) = +000000777777
	NZJ	ZOP	1	Wait if no Data Available
NXTWRD	LIC	NXTWRD		
	BRG	(0000)		Pick Up SDHE Word to Compress
	NJP	PARITY		Jump if Parity Error
	STA	DATA		Store SDHE Word in Data
	LIC	A		Set Up Table Lookup
	SIC	PCMA		For Unique ID of Syllables
	JPR	PCMA		
PCMA	HLT	0000		Instruction Never Executed
	BRG	(0000)		
	NJP	SPECPR		Jump if Special Proc. Required
	LIC	A		
	SIC	PCMA	1	Construct and Store Reference Table Lookup Addresses For All Three Data Syllables
	IIC	0000		
	SIC	PCMA		
	IIC	0000	2	Store Reference Words For All Three Data Syllables
PCMA	SIC	PCM		
	BRG	(0000)		
	STA	REFWDA		
	BRG	(0000)		
	STA	REFWDB		
	BRG	(0000)		
	STA	REFWDC		
	BRG	DATA		
	SAC	R		
	LSH	10		Shift First Syllable Into A
	ORL	DMASKA		
	SAC	PCMDTA	2	
	LSH	10		Shift Second Syllable Into A
	ORL	DMASKB		
	SAC	PCMDTA		
	LSH	10		Shift Third Syllable Into A
	ORL	DMASKC		
	SAC	PCMDTA	1	

<u>LOC.</u>	<u>OP.</u>	<u>ADDR.</u>	<u>INC.</u>	<u>COMMENTS</u>
PCMDTA	LIC	BUFTAB		Set IC to Next N-R Load Location
	BRG	(0000)		
	STA	DATAWB		Construct by Table
	BRG	(0000)		Lookup and Store
	STA	DATAWC		"DOUBLE-DATA" Syllables
	BRG	(0000)		
	STA	DATAWA		
	SUB	REFWDA		
	AND	SMASK		(SMASK) = -001 000 000 000
	ADD	PCMKA		(PCMKA) = +776 777 777 777
PCMSB	NZJ	NRA		Jump if First Syllable N-R
	BRG	DATAWB		
	SUB	REFWDB		
	AND	SMASK		
	ADD	PCMKA		
	NZJ	NRB		Jump if Second Syllable N-R
PCMSC	BRG	DATAWC		
	SUB	REFWDC		
	AND	SMASK		
	ADD	PCMKA		
	NZJ	NRC		Jump if Third Syllable N-R
	BRG	NXTWRD		
	ADD	ONE		
	STA	NXTWRD		Increment Address
	SUB	BUFULL		
	NJP	END		Jump if not end of Buffer
	BRG	NXTSRT		
	STA	NXTWRD		
END	JPR	ZOP		Exit From ZOP Subroutine
NRA	BRG	COUNT		
	AND	ONE		
	NZJ	CNTODD		Jump if Count Odd
	BRG	DATAWA		Even Count
	BRG	REFWDA		
	RSH	14		Right Shift 12 Bits
	BRG	R		
	AND	MSMASK		MSMASK = +037777600000
	JPR	BUFTAB	1	
CNTODD	BRG	DATAWA		
	BRG	REFWDA		
	LSH	10		Left Shift 8 Bits
	AND	LSMASK		(LSMASK) = 177777

<u>LOC.</u>	<u>OP.</u>	<u>ADDR.</u>	<u>INC.</u>	<u>COMMENTS</u>
	11C	0000		
	JPL	BUFTAB		
BUFTAB	SIC	BUFTAB		
	ORL	(0000)		or with MS Half
	SIC	BUFTAB	1	
	STA	(0000)		Store Compressed Data Word
	BRG	COUNT		
	ADD	ONE		
	STA	COUNT		Increment Count
	BRG	PCMA		
	ADD	PCMKB		
	STA	LIMTAB		
	LIC	PCMA		
	SIC	LIMTAB	1	
LIMTAB	BRG	DATAWA		
	AND	(0000)		
	NJP	NEGLIM		JUMP IF $X_0 - K < 0$
	STA	(0000)		Store New Reference Limits
	STA	R		
	AND	ULMASK		ULMASK = +001000000000
	NZJ	POSLIM		JUMP IF $X_0 + K > 2^8 - 1$
	JPR	PCMSB		Finished with First Syllable
NEGLIM	AND	NGMASK		(NGMASK) = +001777777777
	JPR	LIMTAB	1	
POSLIM	BRG	R		
	AND	PSMASK		(PSMASK) = -777001777777
	JPR	LIMTAB	1	

SUMMARY OF ZOP PROCESSING BY AD/ECS-37

<u>FUNCTION</u>	<u>Number of AD/ECS-37 Cycles Required</u>
Input Uncompressed SDHE Word from PCM/DHE and Store in Input Buffer	67
Access Oldest SDHE Data Word from Buffer and Perform ZOP Processing on All Three Data Syllables (Assume All Syllables Redundant)	318
Perform Special Processing Required for Each Nonredundant Data Syllable	135

In this format the least significant 26 bits in the computer register contain the received SDHE word. The most significant bit is an odd parity bit generated by the PCM/DHE on the current contents of the Computer Register. Since the 26 bit SDHE word was already encoded with odd parity, the most significant bit should always be "0". A "1" in this position indicates a parity error in the received SDHE word. Bit 7 is a frame sync indicator and will be a "1" only during the word time in which an acceptable replica of the frame sync pattern is received. Bit 9 represents frame sync lock and will be a "1" whenever the frame sync detector is in the "Lock Mode". Bits 6 and 8 are the complements of bits 7 and 9 respectively, and are included only to insure that there is even parity for the 4 bit control field (bits 6, 7, 8 and 9).

B.2.1.3 Control and Data Signals from PCM/DHE

Thirty seven (37) data lines which describe the logical state of each of the 37 bit positions of the PCM/DHE Computer Register will be brought out in parallel to an external connector of the PCM/DHE. The control signals which will be brought out to an external connector will include but not be limited to the following signals:

- (1) a "Data Ready" signal signifying that a new word has been entered into the Computer Register; and
- (2) an "Inhibit Read" signal signifying that the state of the Computer Register is currently changing.

B.2.1.4 Signal Characteristics and Cabling

The DCU shall be implemented to accept the standard signal characteristics (logic levels, impedances, rise times, etc.) and tolerances generated by the Magnavox PCM/DHE. The DCU will include the necessary cabling and connectors to interface with the external PCM/DHE connectors.

Appendix B

RECOMMENDED SPECIFICATIONS FOR SDHE DATA COMPRESSOR UNIT

B.1 Introduction

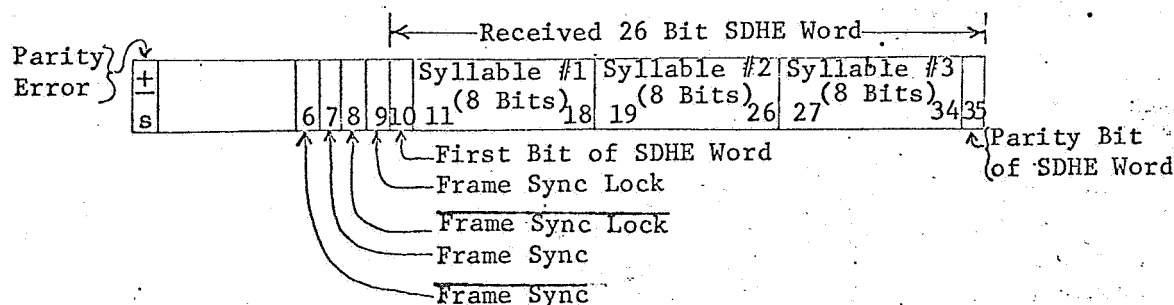
The SDHE Data Compressor Unit (DCU) shall consist of a decommutation and preprocessing subsystem, a data compression subsystem and such other additional logic, interface and cabling equipment as is required to decommutate and compress OAO SDHE telemetry data received from the Magnavox PCM/DHE and to output the nonredundant compressed data to the General Mills AD/ECS-37 computer. The DCU shall contain a self-contained reference memory which may be reloaded under the control of the AD/ECS-37.

B.2 System Interfaces and Signal CompatibilityB.2.1 Magnavox PCM/DHE to DCU InterfaceB.2.1.1 General

The DCU shall interface with the Magnavox PCM/DHE and shall be capable of transferring data from the 37 bit DHE Computer Register to the DCU.

B.2.1.2 Data Format

The patchboard of the Magnavox PCM/DHE shall be wired to assemble OAO SDHE data in the DHE Computer Register in the format given below.



B.2.1.5 Input Data Rates

The DCU shall be designed to accept SDHE telemetry data from the PCM/DHE and to perform all decommutation, preprocessing and data compression functions described in this Specification at a maximum input bit rate (to the PCM/DHE) of not less than 66,688 bits/s. This rate is the same as the rate at which the recorded OAO SDHE data is played back to the ground station. It should be noted, however, that the anticipated ground station configuration will not be capable of accepting the compressed data output from the DCU at uncompressed input rates greater than 33,344 bits/s.

B.2.2 DCU to AD/ECS-37 Interface for Compressed Data Transfer

B.2.2.1 General

The DCU shall be designed to interface with the AD /ECS-37 computer for the purpose of transferring to the computer the compressed SDHE data. This data transfer shall be accomplished in blocks of 64 AD/ECS-37 words through the BI buffer.

B.2.2.2 Compressed Data Buffering

The DCU shall compress the SDHE telemetry data using the algorithm described in Sec.B.4.1. The compressed data output will be initially buffered in blocks equivalent to 64 AD/ECS-37 words within a self-contained memory of the DCU.

B.2.2.3 Compressed Data Word Format

The DCU shall load the BI buffer with 64 words of compressed data in the format shown below.

<First Compressed Word>			<Second Compressed Word>		
Blank	Address #1	Magnitude #1	Address #2	Magnitude #2	
s.o	34 (8 Bits)	11 12 (8 Bits)	19 20 (8 Bits)	27 28 (8 Bits)	35

B.2.2.4 Control and Data Signals

The AD/ECS-37 will initiate the transfer of a block of compressed SDHE data from the memory of the DCU to the BI buffer by executing an external machine instruction of the form "61 XX20" where XX is a 6 bit address assigned to the DCU. If upon receiving this command an entire block of compressed data has been assembled and is ready to be transferred to the computer, the DCU will respond by initiating the data transfer. On the other hand, if an entire block has not been assembled, the DCU will wait until the block is completed and will then initiate the data transfer. (See Sec.B.4.2 for more discussion on this point.)

The data transfer from the memory of the DCU to the BI buffer will be performed in 6 bit parallel characters. The loading of one equivalent AD/ECS-37 word will require eight character transfers consisting of one sign character, six data characters and one end-of-word control character. The DCU will also receive character acknowledge signals from the BI buffer and will respond to these signals by initiating the next character transfer. The DCU will generate the "Cycle BI" signals necessary to store the data in BI.

B.2.2.5 Signal Characteristics and Cabling

The Output Control Logic of the DCU shall be designed to accept and generate signal waveforms with the standard characteristics (logic levels, impedances, rise times, etc.) and tolerances specified in the "AD/ECS-37 Input/Output Manual". The DCU will include the necessary cabling and connectors to interface with the BI buffer.

B.2.2.6 Input Data Rate to BI Buffer

The data transfer to the BI buffer will be synchronized by the clock of the BI buffer which nominally runs at a 50 kHz rate. The DCU will not introduce any appreciable further delay in the data transfer rate.

B.2.3 AD/ECS-37 to DCU Interface

B.2.3.1 General

The capability shall exist for the AD/ECS-37 to load any or all locations of the DCU reference memory by means of a data transfer through the BA buffer. It shall be possible to perform this function coincident with the reception and compression of SDHE data.

B.2.3.2 Data Format and Control

To load any location in the DCU reference memory the AD/ECS-37 will initiate the following two actions:

- (1) load a word into BA of the form "+00 LLLL 00 0DDD" where LLLL represents the location in the reference memory to be loaded and DDD represents the 8 bit data quantity to be stored in the addressed location; and
- (2) execute an external machine instruction of the form "61 XX31" where XX is the same six bit address code referred to in Sec. B.2.2.4.

The DCU shall be designed to accept reference data changes initiated in the manner described above and to perform the reference data storage function. The DCU will generate the control and acknowledge signals necessary for the proper transfer of reference data from the BA buffer to the DCU.

B.2.3.3 Signal Characteristics and Cabling

The DCU shall be designed to accept and generate signal waveforms with standard characteristics (logic levels, impedances, rise times, etc.) and tolerances specified in the "AD/ECS-37 Input/Output Manual". The DCU will include the necessary cabling and connectors to interface with the BA buffer.

B.3 SDHE Decommulation and Preprocessing

B.3.1 General

The DCU shall include such logic and equipment necessary to uniquely identify the source of each telemetry measurement included in the SDHE telemetry format and to perform other logical operations on various SDHE words necessary to assemble this data in a standard format for entry into the Data Compression Subsystem.

B.3.2 Decommulation

The SDHE frame format has provisions for various types of sub-commutation. Because of this, a given syllable in the SDHE frame will, in general, contain a measurement from a different sensor on successive frames. The Decommulation Subsystem of the DCU will be concerned with constructing a unique sensor address to be associated with each sensor measurement.

B.3.2.1 Main Frame (MF) Word Counter

The Decommulation Subsystem will contain a 6 bit MF Word Counter for the purpose of aiding the identification of the received data. This counter will be initially set to 63_{10} whenever a Frame Sync Indicator (bit 7) appears in a word transferred from the PCM/DHE and will be incremented by one on each subsequent word transfer.

B.3.2.2 Synchronous Decommulation

The Program Code field of MF Word 2 contains a field of seven bits (not consecutive) which describe the subcommutation phase of the various data sections of the current frame. The DCU will extract this field from the received SDHE frame and use this information to construct unique sensor addresses for the sensors monitored on the current frame. The bi-level word contained in MF Word 30 is sub-subcommutated; however, the Program Code

field does not identify the current phase of this word. To construct sensor addresses associated with this word it is necessary to extract a three bit field from MF Word 29 to identify MF Word 30.

MF Word 30

One of five different sets of bi-level sensors may be monitored on MF Word 30. The decommutation process will examine three bits of MF Word 29 to identify the current set.

MF Words 31 and 32

One of two different sets of bi-level sensors may be monitored on MF Words 31 and 32. Program Code field specifies current set.

MF Words 33 to 52 (Operational or Environmental Analog Group)

One of two different sets (Operational or Environmental) of analog sensors will be monitored on MF Words 33 to 52. Program Code field specifies current set.

MF Words 53 to 64 (Analog Groups A, B, C or D)

One of four different sets of analog sensors will be monitored on MF Words 53 to 64. Program Code field specifies current set.

B.3.2.3 Asynchronous Decommutation

MF Words 3 to 26 contain 24 gimbal angle measurements (twelve "Commanded" angles and twelve "Error" angles). A given gimbal angle will not be monitored on the same MF word for each frame. To decommutate this data it is necessary to make use of the following facts:

- (1) the odd numbered words in this portion of the SDHE frame (i. e., 3, 5, 7, . . . 25) contain the "Commanded" angles and a seven bit field within these words specify the specific gimbal angle; and

- (2) the even numbered words (4, 6, 8, . . . 26) contain the "Error" angles. The gimbal to be associated with each of these "Error" angles is the same as that identified in the preceding "Commanded" angle word.

In addition, the cyclic sequence of the gimbal measurements is fixed and therefore the gimbal sequence for any single frame can be determined by examining the address portion of MF Word 3.

B.3.3 Preprocessing

Because of the various anomalies within the SDHE frame format, it is necessary to perform a preprocessing operation on the received data in order to present the SDHE data to the Data Compression Subsystem in a standard format.

B.3.3.1 Data Inhibit

In a system employing data compression it is extremely important to insure that the input data be properly received and framed prior to the data compression operation. When the quality of data is questionable it is far better to inhibit the data compression function rather than to attempt data compression on data that is either incorrectly received or improperly framed. The DCU shall make use of the quality control indicators transferred by the PCM/DHE along with the SDHE word as specified in the format described in Sec. 2.1.2. No data shall be forwarded to the Data Compression Subsystem if either or both of the following conditions have occurred:

- (1) A parity error is detected in the SDHE word
(Sign bit of PCM/DHE Computer Register = "1").
- (2) Frame Sync Dropout (Bit 8 = "1").

B.3.3.2 Star Tracker Status

Two bits of star tracker status information are included in each of the twelve "Error" gimbal angle words. Since this status data is not monitored

any other place in the SDHE frame, it is necessary to extract this data from the "Error" gimbal words. It is suggested that the 24 bits of star tracker status data be assembled together in a standard order by the Preprocessing Subsystem and subsequently handled as an extra bi-level word. However, other arrangements which provide for the data compression and transmission of the star tracker status will be allowed.

B.4 Data Compression

The DCU shall have the operating characteristics of the DACOM DT-110 or equivalent.

B.4.1 Compression Algorithms

B.4.1.1 Zero Order Predictor (ZOP)

The DCU will receive fully decommutated and preprocessed data from the Decommutation Subsystem and will perform a Zero-Order Predictor (ZOP) test on each 8 bit data syllable. The DCU will contain a reference memory in which the last previously transmitted value of each sensor and the individual sensor tolerance limits are stored. If the ZOP test reveals that the current data point is redundant, no further processing is required on that data syllable. On the other hand, if the ZOP test reveals that the syllable is nonredundant, the DCU will store the 16 bit compressed data word (8 bit sensor address and 8 bit magnitude) in an output data buffer and will update the reference memory location associated with that sensor to reflect the new sensor reference value.

B.4.1.2 Other Compression Algorithms

While it is anticipated that the ZOP algorithm will be the principal algorithm used for SDHE data compression, the DCU will have the capability of also performing the following algorithms.

Fixed Limits (FL)

If y_n is the present sample value, y_o is the midpoint of the limits corridor (a programmed constant), and K is one half the corridor amplitude, then y_n is output if $|y_n - y_o| \geq K$.

Fixed Threshold (FT)

If y_n is the present sample value, y_o is the threshold value (a programmed constant), then y_n is output if $y_n \geq y_o$.

Delta Threshold (DT)

If y_n is the present sample value, y_o is the last previous data value ($y_o = y_{n-1}$), and K is the threshold, then y_n is output if $|y_n - y_o| \geq K$. The new value of y_o becomes y_n .

Automatic Jump to ZOP (JZOP)

Channels may be individually programmed to switch to ZOP when a data sample is nonredundant and the programmed algorithm is FL, FT, or DT.

Pass All Data (PAD)

Channels may be individually programmed to pass all data samples by using the ZOP algorithm with tolerance $K = 0$.

Reject All Data (RAD)

Channels may be individually programmed to reject all data samples by using the ZOP algorithm with tolerance K set equal to full scale.

B.4.2 Compressed Data Buffering and Output Control

The compressed data generated by the ZOP processor will be stored in one of two compressed output buffer areas of the DCU core memory. These two buffer areas will be referred to as Buffer 1 and Buffer 2 respectively. Each buffer area will be capable of storing 128 16-bit compressed data words.

Immediately following the start of the SDHE data compression operation, the ZOP processor will begin filling Buffer 1 with the compressed SDHE data. After 128 compressed data words have been loaded into Buffer 1, the ZOP processor will begin filling Buffer 2. After Buffer 2 has been filled, the ZOP processor will switch back to Buffer 1 and begin reloading that buffer. The buffer loading will continue to alternate between Buffers 1 and 2 as long as the ZOP processor continues to generate compressed data.

Whenever the AD/ECS-37 computer executes a "61 XX20" instruction (see Sec.B.2.2.4), the Output Control Logic will initiate a transfer to BI of the buffer which is not currently being filled by the ZOP processor unless the contents of this buffer has already been read out to BI as a result of a previous "61 XX20" instruction. In the case where two or more "61 XX20" instructions are executed while the ZOP processor is filling Buffer 2, the first "61 XX20" instructions will cause the initiation of the transfer of Buffer 1 to BI, the second "61 XX20" will cause a control flip-flop to be set such that Buffer 2 will be read out to BI as soon as the ZOP processor switches back to filling Buffer 1, and all subsequent "61 XX20" instructions will be ignored.

When a data transfer to BI is initiated the Output Control Logic will sequentially access the compressed data in the specified buffer area and will control the transfer of this data to BI in the format and manner specified in Secs. B.2.2.3 and B.2.2.4.

B.5 Additional Control Capability

B.5.1 GMT Time Tagging

In addition to processing and compressing the spacecraft time word which is contained in the SDHE frame, the capability shall exist to interleave a GMT word with the compressed data. This GMT word will represent the time that the current portion of the SDHE data was processed by the DCU.

B.5.2 Remote Control

The capability shall exist to start, stop or reset the DCU under remote control of the AD/ECS-37.

B.6 Mechanical, Power and Environmental Specifications

B.6.1 Mechanical

The DCU shall be designed to be mounted on standard size (19 inch) racks and shall not exceed 36 inches in the vertical dimension.

B.6.2 Power

The DCU shall operate from a 110 VAC \pm 5 percent, 15 amp, single phase source.

B.6.3 Environmental

The DCU shall operate under the following environment conditions:

Temperature: 0° to 50° C.

Relative Humidity: 0 to 90 percent (without condensation).

Appendix C

ANALYSIS OF PROBABILITY OF OCCURRENCE OF
RETRANSMISSION REQUESTSC.1 General

Table 5 of Ref. 6 contains a summary of error performances of 28 selected NASCOM data circuits during the three month period beginning February 1, 1967. The test was run using the Western Electric data modem Model 205B over communication channels similar to those which will be installed to Quito and Santiago. The average bit error rate observed over this period (which represented a total of 1380 hours of testing) was 1.77×10^{-5} . Except for two circuits between Corpus Christi and NASA/GSFC all other circuits either originated or terminated outside the continental United States.

In analyzing the probability of retransmission requests we will assume that the bit error rate of the channel is 1.77×10^{-5} and that there is no bursting of errors. This latter assumption is actually a worst case assumption since it tends to spread the bit errors over many blocks rather than clustering them in a relatively few blocks.

Retransmission requests could be handled in a number of different ways. Two ways that immediately present themselves are the following:

1. Upon detecting an incorrectly encoded block (or a correctly encoded block with an unproper sequence number) the receiving terminal will transmit a retransmission request and will then ignore all subsequently received block until it receives a properly encoded block with the correct sequence number, or
2. Upon detecting an incorrectly encoded block (incorrect check-bits or sequence number) the receiving terminal will transmit a retransmission request but will continue to decode all incoming blocks. When the requested block is repeated and correctly received back at the receiving terminal, the computer at the receiving terminal will then insert the repeated block in front of the other blocks that were correctly received during the processing of the retransmission request.

The latter procedure is somewhat more efficient from a data transmission standpoint but it does greatly complicate the software at both the transmitting and receiving terminals. Due to the fact that the probability of an error in a block is quite low there appears to be little justification of this added complexity. For this reason it is suggested that the first procedure be implemented.

Whenever a retransmission request is received back at a remote site the AD/ECS-37 will immediately terminate whatever block it is currently transmitting and will initiate a retransmission of the requested block following the block initially received in error.

C. 2 Analysis of Optimum Data Block Length

For the purpose of analyzing the optimum size block length of the format described in Sec. 5.2.1, let us assume that the average delay between the completion of the transmission of a given block and the time that a retransmission request is received, decoded and recognized for that same block is 0.5 seconds. Because of the NASCOM header and DTS sync bits the communication channel can only accept 1792 bits/s from the AD/ECS computer. The data blocks transferred from the AD/ECS to DTS encoder will be an integral number (N) of 16 bit words where $8 \leq N \leq 64$. The header information and error detection checkbits will require 6 16 bit words in each of these blocks. If there were no retransmission requests then the actual information transfer rate over the line would be

$$\frac{16(N-6)}{16N} \times 1792 \text{ bits/s}$$

However, whenever an error occurs the block in error must be repeated along with 1/2 second of data transmitted following the block in error. The probability $p(N)$ that a block composed of N 16 bit words will contain one or more bit errors if we assume a binary symmetric channel with bit error rate; ϵ , is simply

$$p(N) = 1 - (1 - \epsilon)^{16N} \approx 16N \epsilon \quad \text{for } 16N \ll \frac{1}{\epsilon} \quad (C-1)$$

If no errors occur in the transmission the time required to transmit an N word block over the communication channel is $16N/1792$ seconds. If an error were to occur on the first transmission of a block and if the block were received correctly on the first retransmission then the total time that the communication circuit devoted to that block is $(2 \times 16N/1792) + 0.5$ sec. Since the bit error rate is quite low we will neglect the effect of multiple block retransmissions. The average time required for an N word block to be successfully transmitted is

$$\bar{t}(N) = (1 - 16N\epsilon) \cdot \left(\frac{16N}{1792}\right) + (16N\epsilon) \cdot \left(\frac{32N}{1792} + \frac{1}{2}\right) \quad (C-2)$$

Since each correctly received N word block contains $16(N-6)$ information bits, the average rate, $R(N)$, at which correctly transmitted data is received at the OAO control center is

$$R(N) = \frac{16(N-6)}{(1 - 16N\epsilon) \left(\frac{16N}{1792}\right) + 16N\epsilon \left(\frac{32N}{1792} + \frac{1}{2}\right)} \quad (C-3a)$$

$$= \frac{(N-6) \cdot 1792}{N(1 + 16N\epsilon + 896\epsilon)} \quad (C-3b)$$

For $\epsilon = 1.77 \times 10^{-5}$ we have

$$R(N) = \frac{1792(N-6)}{N(1.01585 + 2.83 \times 10^{-4}N)} \quad (C-4)$$

To find the optimum block size we set $\frac{dR}{dN} = 0$ and solve for N . From this computation we find $N_{OPT} = 152$. However, because of format constraints $8 \leq N \leq 64$. Thus the optimum block length subject to this constraint is 1024 bits or 64 16 bit words.

C.3 Average Effective Information Bandwidth

The average effective data transmission rate of information from the remote site to the OAO Central Control Center can be found from Eq. C-4. For $N = 64$ this yields an average information transfer rate of 1570 bits/s. This figure includes the effect of: (1) the DTS formatting overhead; (2) the additional overhead imposed by the format described in "Data Block Format" on page 29; and (3) the effect of transmission errors assuming a bit error rate of 1.77×10^{-5} .